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SWOE

Yuma I Information Base For Generation of Synthetic Thermal Scenes

Jerrell R. Ballard, Jr.

U.S. Army Engineer Waterways
Experiment Station
Vicksburg, MS

SWOE Report 94-4
June 1994

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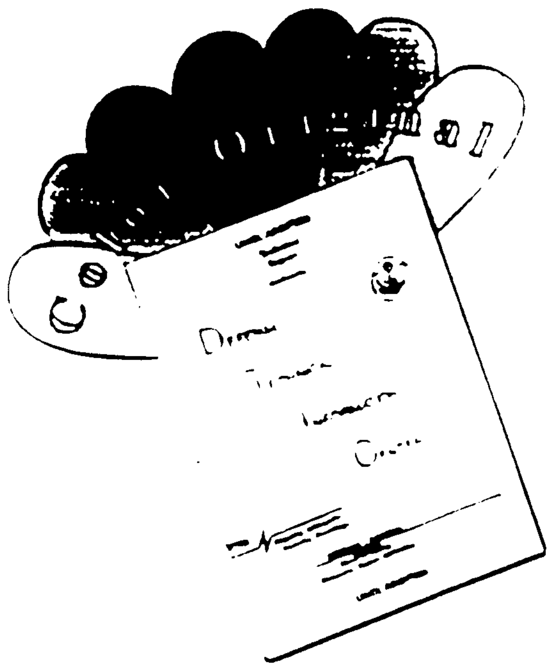

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FOREWORD

SWOE Report 94-4, June 1994, was prepared by J.R. Ballard, Jr. of U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

This report is a contribution to the Smart Weapons Operability Enhancement (SWOE) Program. SWOE is a coordinated, Army, Navy, Marine Corps, Air Force and ARPA program initiated to enhance performance of future smart weapon systems through an integrated process of applying knowledge of the broadest possible range of battlefield conditions.

Performance of smart weapons can vary widely, depending on the environment in which the systems operate. Temporal and spatial dynamics significantly impact weapon performance. Testing of developmental weapon systems has been limited to a few selected combinations of targets and environmental conditions, primarily because of the high costs of full-scale field tests and limited access to the areas or events for which performance data are required.

Performance predictions are needed for a broad range of battlefield environmental conditions and targets. Meeting this need takes advantage of significant DoD investments by Army, Navy, Marine Corps and Air Force in 1) basic and applied environmental research, data collection, analysis, modeling and rendering capabilities, 2) extensive target measurement capabilities and geometry models, and 3) currently available computational capabilities. The SWOE program takes advantage of these DoD investments to produce an integrated process, the SWOE Process.

SWOE is developing, validating, and demonstrating the capability of the SWOE Process to handle complex target and environment interactions for a broad range of battlefield conditions. SWOE is providing the DoD smart weapons and autonomous target recognition (ATR) communities with a validated capability to integrate measurements, information bases, modeling, and simulation techniques for complex environments. This is a DoD-wide partnership that works in concert with advanced weapon system developers and major weapon system test and evaluation programs.

The SWOE program started in FY89 under Balanced Technology Initiative (BTI) sponsorship. Present sponsorship is by the U.S. Army Corps of Engineers (lead service), the individual services, and the Joint Test and Evaluation (JT&E) program of the Office of the Director of Test & Evaluation, Office of the Under Secretary of Defense OUSD(A/DT&E).

The Joint Test Director is Dr. J.P. Welsh. The Deputy Test Directors are: (Army) LTC Jerre Wilson and (Air Force) Maj Richard Jennings. The Integration Manager is Mr. Richard Palmer. The Modeling Configuration Manager is Dr. George G. Koenig.

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13. ABSTRACT *(Maximum 200 words)*

Procedures are being developed for the environmental information base component of the Smart Weapons Operability Enhancement/Joint Test and Evaluation (SWOE/JT&E) Program analytical thermal infrared scene generation procedure at the U.S. Army Yuma Proving Ground, Arizona. Scope is limited to documentation of the information base content and data processing/analysis procedures developed to satisfy other component requirements such as thermal signature modeling, thermal radiance field predictions, and generation of realistic graphic representations of the three-dimensional thermal backgrounds.

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Preface

The study reported herein was conducted during the period July 1993 to October 1993 by personnel of the Natural Resources Division (NRD), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The study was authorized by Dr. J. P. Welsh, Joint Test Director, Smart Weapons Operability Enhancement (SWOE) Joint Test and Evaluation Program (JT&E) Office, Hanover, NH.

WES has prepared three technical reports on Yuma 1 in support of the SWOE/JT&E Program. These are as follows:

a. "Yuma 1 Information Base for Generation of Synthetic Thermal Scenes"

b. "Yuma 1 Site Characterization and Data Summary"

c. "Analysis of Thermal Imagery Collected at Yuma 1, Yuma, Arizona"

Mr. Jerrell R. Ballard, Jr., Environmental Characterization Branch (ECB), NRD, was Principal Investigator and was responsible for design and development of the digital information base and data analysis procedures. Messrs. John F. Manby, Jr., Mark R. Graves and Scott Bourne and Dr. M. Rose Kress, ECB, contributed to data analysis. Mr. Ballard prepared the report.

The work was conducted under the general supervision of Mr. Harold W. West, Chief, ECB; Dr. Robert M. Engler, Chief, NRD; and Dr. John Harrison, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or kelvins[1]
feet	0.3048	meters
inches	2.54	centimeters

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F - 32). To obtain kelvin (K) readings, use: K = (5/9) (F - 32) + 273.15.

1 Introduction

Background

The Smart Weapons Operability Enhancement/Joint Test and Evaluation (SWOE/JT&E) Program is a multiservice (U.S. Army, Navy, and Air Force) initiative aimed at providing the technology to simulate complex environmental backgrounds for use by smart weapons designers, developers, and testers. The smart weapons being designed to locate and acquire targets automatically must be able to isolate targets in relatively complex and varied environmental scenes. The technology provided by the SWOE/JT&E program will enhance the ability to characterize the effects of various terrain and atmospheric conditions on the smart weapons sensor performance.

Purpose and Scope

The purpose of this report is to document the methods used and developed for the information base component of the SWOE/JT&E thermal infrared scene generation procedure. This report is limited to the documentation of the information base content and procedures used to develop the Yuma 1 information base. The numerical models and other main components of the SWOE/JT&E thermal infrared scene generation procedure will be described in other reports.

Site Location

The U.S. Army Yuma Proving Ground (YPG), Figure 1, is located in the extreme southwest corner of Arizona. The SWOE/JT&E site is on the Kofa Firing Range in the Castle Dome Plain, the vast alluvial fan surrounding Castle Dome Mountain. The site is a portion of the area referred to as the Wide Area Mine (WAM) test area described in a previous U.S. Army Engineer Waterways Experiment Station (WES) report (see Sabol et al. 1989). The Castle Dome Plain is typified by an extensive wash network separated by large patches of desert pavement. Vegetation is sparse and clustered near the drainage channels. The landscape area considered for the information base is approximately 1.78 by 0.57 km with local relief of about 5 m. All geographic

data were projected into the universal transverse Mercator (UTM) projection in zone 14 and referenced to the North American Datum 1927 (NAD27).

The climate at YPG is generally arid and hot. Low humidity prevails in the summer; winters are mild and more humid. Daytime temperatures in the summer normally exceed 100 °F; daytime winter temperatures average about 55 °F (Sabol et al. 1989).[1]

[1] A table of factors for converting non-SI units of measurement to SI units is presented on page vi.

2 Information Base Design and Content

Information Base Function

The function of the Yuma 1 information base in the SWOE/JT&E thermal infrared scene generation procedure is to provide all spatial and tabular data required by each component in the procedure. This requires providing descriptive environmental data on all combinations of terrain and atmospheric conditions within the designated geographical area.

The information base utilizes the concept of landscape units to describe the environmental conditions of the terrain. This landscape unit and its development is described in detail in Kress (1992). This report provided guidance on determining relevant environmental factors necessary for the Yuma 1 information base.

Information Base Content

The information base contains four kinds of digital data: terrain (e.g., topography, soil types, soil moisture, and vegetation types); meteorological data (e.g., air temperature, visibility, and cloud cover); three-dimensional (3-D) geometric tree models; and texture data. Digital data used in the SWOE scene generation procedure are stored in SWOE/JT&E specific formats described in Appendix A.

Digital terrain data are representations of the geographical area's surface stored in computer-compatible formats. These data depict characteristics such as elevation, vegetation types, soil types, slope, slope-aspect, and other relevant environmental information.

Meteorological data are required during the thermal infrared scene generation procedure and have influence on thermal model predictions (Balick, Link, and Scoggins 1981; Smith et al. 1981). Data collected from multiple sites (Hahn 1994) was averaged hourly and used as input to the scene generation procedure.

Three-dimensional vegetation geometric tree model data are representations of predominant 3-D features (trees and bushes) in the area. The data are typically representations of vegetation (trees and bushes) taller than 0.5 m.

The thermal prediction models (Hummel et al. 1991) used in the SWOE/JT&E scene generation procedure require as inputs complete descriptions of the physical and thermal attributes of each landscape unit. These data are provided in tabular format for each landscape feature.

3 Information Base Development

As the first step in the development of the Yuma 1 information base, a list of factors required by each thermal prediction model pertaining to the environment was compiled. This process resulted in a list of environmental factors for generation of synthetic scenes. Specification of the factors and their data types defined the information base content and development specifications. Listed in Table 1 are the factors contained in the Yuma 1 information base.

Terrain Data

Six digital terrain data files are required in the SWOE scene generation procedure: topographic elevation, ground slope magnitude, slope aspect, vegetation type, and surface and subsurface soil type. These data files are described below.

Topographic elevation

Digital topographic elevation data define the basic 3-D geometry of the landscape and are used directly during generation of synthetic scenes. High resolution elevation contour data used were obtained previously by WES for the WAM program (Sabol et al. 1989). The 1:2,400-scale, 2-ft topographic elevation contour map was produced by the Mapping Branch of Tennessee Valley Authority, under contract to WES, using the 1:12,600-scale black and white photography (Sabol et al. 1989). The map, which required 20 stereo pairs to produce, conforms to the U.S. Geological Survey National Map Accuracy Standard for vertical and horizontal control (American Society of Photogrammetry and Remote Sensing 1980). As defined by this study, the maximum elevation relief within the geographical area is approximately 20 m.

The topographic elevation contour map data along with supplemental field survey elevation data acquired by WES for SWOE (Hahn 1994) were imported into the Environmental Systems Research Institute (ESRI) ARC-INFO system and transformed into a triangular irregular network (TIN). The TIN data were

Table 1
Yuma 1 Information Base Content

Topographic elevation
Ground slope magnitude
Slope aspect
Vegetation Type
Grass
Percent ground cover
Height
State - measure of plant vigor
Long-wave emissivity
Shortwave absorptivity
Forest canopy
Stomatal resistance
Long-wave emissivity
Shortwave absorptivity
Long-wave transfer coefficient
View angle matrix
Surface and Subsurface Soil Type
Number of nodes in layer
Quartz content of soil
Roughness length
Bulk transfer coefficient for eddy diffusivity
Turbulent Ptandtl number
Turbulent Schmidt number
Windless convection coefficient
Shortwave absorptivity
Intrinsic density of dry material
Bulk density of dry material
Heat capacity of dry mineral solids
Dry soil thermal conductivity
Soil coarseness code
Plasticity index
(Sheet 1 of 3)

Table 1 (Continued)
Albedo
Hemispherical emissivity
Thermal diffusivity
Temperature of nodes
Thickness of nodes
Total bulk water density
Meteorological
Latitude of recording station
Longitude of recording station
ZULU time difference
Elevation of recording station
Height above ground of recording station
Averaged surface albedo of landscape area
Time interval of data
Year
Julian day
Local hour, time
Atmospheric pressure
Air temperature
Relative humidity
Wind speed
Wind direction
Visibility
Global incoming solar radiation
Direct incoming solar radiation
Diffuse incoming solar radiation
Downwelling thermal infrared radiation
Low cloud cover, percent
Low cloud cover, type
Midlevel cloud cover, percent
Midlevel cloud cover, type
High cloud cover, percent
High cloud cover, type
(Sheet 2 of 3)

Table 1 (Concluded)
Precipitation type
Precipitation rate
Precipitation grain size
(Sheet 3 of 3)

interpolated to produce a 1-m elevation grid array covering the 1.78- by 0.57-km area. The resulting 1-m elevation grid array was developed using the 2-ft contour map data as depicted in Figure 2.

Ground slope magnitude and slope aspect

Ground slope magnitude is defined as the inclination of the terrain surface from horizontal. Slope aspect, the orientation of the surface normal, is referenced clockwise from true north. Slope and slope-aspect are used to determine the solar radiation incident to the earth's surface that affects thermal signature. Values for both are required in the synthetic scene generation procedure for each landscape unit.

Digital terrain data depicting slope and slope-aspect values were calculated using the generated 1-m topographic elevation data. A slope value in degrees and a slope-aspect value expressed as degrees from true north (ESRI ARC-INFO) were calculated for each 1- by 1-m grid cell within the elevation data array.

Numerical model sensitivity in the SWOE scene generation procedure made it necessary to reduce the spatial variability in the slope and slope-aspect digital terrain data by grouping values into a limited number of classes. For each grid cell, the slope and slope-aspect value was reassigned to an appropriate class. The class ranges are listed in Tables 2 and 3. Class midpoints are used during numerical calculations of surface temperatures and radiances. Figures 3 and 4 illustrate the distribution of the slope and slope-aspect classed values, respectively, within the 1.78- by 0.57-km area.

Vegetation types

Thermal prediction models are available for nonvegetated areas (bare ground), short grass, medium-height grass, coniferous and deciduous forests canopy, and individual (isolated) trees and bushes. All vegetation within the landscape area were assigned one of these four types.

A vegetation type map, compatible with the capabilities of the current SWOE/JT&E thermal prediction models, was prepared from vegetation data

Table 2 Class Ranges for Terrain Slope			
Class	Class Range, deg	Slope Value Used for Calculation	Area Covered percent
1	0 to 5	3.0	90.5
2	> 5 to 10	8.0	8.2
3	>10 to 15	13.0	1.0
4	>15 to 20	18.0	0.2
5	>20	23.0	0.1

Table 3 Class Ranges for Slope-Aspect			
Class	Class Range, deg	Aspect Values Used for Calculation	Area Covered percent
1	1 to 90	45	10.3
2	91 to 180	135	23.9
3	181 to 270	225	40.9
4	271 to 360	315	24.9

collected during the WAM program (Sabol et al. 1989). These data were field checked, and 1-m vegetation grid data were generated. Figure 5 illustrates the landuse distribution and includes a nonvegetation (bare ground) category. Table 4 shows the types and descriptions of vegetation.

Surface and subsurface soil types

A ground-based survey during the WAM program revealed two major terrain types in the vicinity of the area, namely desert pavement and washes. Desert pavement consists of flat, dark-colored, gravelly surfaces with little or no vegetation. Ephemeral washes include areas eroded by flooding; washes contain sand and fine-grained materials in addition to gravel and desert-type vegetation. Additional ground-based surveys revealed that the ephemeral washes were of three types: developed washes, secondary washes, and pavement washes. Developed washes consist of eroded channels generally 1 to 4.5 m wide and 0.5 to 1.5 m deep. Generally, shallower, secondary washes connect with developed washes and are generally shallower than developed washes. Disturbed pavement washes were considered headwater washes extending into the flat desert pavement areas (Sabol et al. 1989).

Table 4
Vegetation Types

Vegetation Type	Description	Area Covered percent
BARE (Nonvegetated)	Bare ground, exposed surface soil	34.9
MVEG	Grass vegetation, medium density	65.1

The four terrain types described were condensed into three by combining pavement washes and secondary washes into the same category for modeling purposes (Table 5). Figure 6 shows the surface soil types occurring within these three surface soil types. All subsurface soil to a depth of 30 cm was determined to be a gravelly silty sand (SM).

Table 5
Soil Types

Soil Type	Description	Percent Cover
ASPT	Desert pavement - sandy silty clay (CL-ML) with trace of gravel	34.87
GRAV	Secondary washes, disturbed desert pavement - gravelly silty sand (SM)	50.73
SAND	Primary washes - silty sand (SM) with gravel	14.40

Composite Terrain Data Layer

The digital terrain data were then used to identify and delineate uniform landscape features. Landscape features are contiguous areas with uniform conditions of surface soil type, subsurface soil type, vegetation type, ground slope, and slope aspect.

A new digital terrain data file was generated that combined the values of the five existing data files by simply assigning a code to each unique combination of existing values that actually occurred. This data file represents a combination of vegetation type, surface soil type, subsurface soil type, ground slope, and slope-aspect. Executed in the Geographic Resources Analysis System (GRASS-GIS), this step resulted in a raster file that was geographically coregistered to the other raster digital terrain files. This processing operation resulted in 59 unique combinations of the five landscape features. Figure 7 shows these combinations and illustrates the complexity of the Yuma 1 information base. Table 6 lists the 59 unique combinations that occurred in the YPG landscape area, their description, and the landscape feature code assigned to each combination.

Table 6
Landscape Feature Codes and Descriptions Present in YPG Study Area

Landscape Feature Code	Vegetation Type	Surface Soil	Subsurface Soil	Ground Slope Value	Slope Aspect Value
001	BARE	ASPT	GRAV	03	045
002	BARE	ASPT	GRAV	03	135
003	BARE	ASPT	GRAV	03	225
004	BARE	ASPT	GRAV	03	315
005	BARE	ASPT	GRAV	08	045
006	BARE	ASPT	GRAV	08	135
007	BARE	ASPT	GRAV	08	225
008	BARE	ASPT	GRAV	08	315
009	BARE	ASPT	GRAV	13	045
010	BARE	ASPT	GRAV	13	135
011	BARE	ASPT	GRAV	13	225
012	BARE	ASPT	GRAV	13	315
013	BARE	ASPT	GRAV	18	045
014	BARE	ASPT	GRAV	18	135
015	BARE	ASPT	GRAV	18	225
016	BARE	ASPT	GRAV	18	315
017	BARE	ASPT	GRAV	23	045
018	BARE	ASPT	GRAV	23	225
019	BARE	ASPT	GRAV	23	315
020	MVEG	ASPT	GRAV	03	135
021	MVEG	ASPT	GRAV	03	315
022	MVEG	GRAV	GRAV	03	045
023	MVEG	GRAV	GRAV	03	135
024	MVEG	GRAV	GRAV	03	225
025	MVEG	GRAV	GRAV	03	315
026	MVEG	GRAV	GRAV	08	045
027	MVEG	GRAV	GRAV	08	135
028	MVEG	GRAV	GRAV	08	225
029	MVEG	GRAV	GRAV	08	315

(Continued)

Table 6 (Concluded)

Landscape Feature Code	Vegetation Type	Surface Soil	Subsurface Soil	Ground Slope Value	Slope Aspect Value
030	MVEG	GRAV	GRAV	13	045
031	MVEG	GRAV	GRAV	13	135
032	MVEG	GRAV	GRAV	13	225
033	MVEG	GRAV	GRAV	13	315
034	MVEG	GRAV	GRAV	18	045
035	MVEG	GRAV	GRAV	18	135
036	MVEG	GRAV	GRAV	18	225
037	MVEG	GRAV	GRAV	18	315
038	MVEG	GRAV	GRAV	23	045
039	MVEG	GRAV	GRAV	23	135
040	MVEG	GRAV	GRAV	23	225
041	MVEG	GRAV	GRAV	23	315
042	MVEG	SAND	GRAV	03	045
043	MVEG	SAND	GRAV	03	135
044	MVEG	SAND	GRAV	03	225
045	MVEG	SAND	GRAV	03	315
046	MVEG	SAND	GRAV	08	045
047	MVEG	SAND	GRAV	08	135
048	MVEG	SAND	GRAV	08	225
049	MVEG	SAND	GRAV	08	315
050	MVEG	SAND	GRAV	13	045
051	MVEG	SAND	GRAV	13	135
052	MVEG	SAND	GRAV	13	225
053	MVEG	SAND	GRAV	13	315
054	MVEG	SAND	GRAV	18	135
055	MVEG	SAND	GRAV	18	225
056	MVEG	SAND	GRAV	18	315
057	MVEG	SAND	GRAV	23	045
058	MVEG	SAND	GRAV	23	225
059	MVEG	SAND	GRAV	23	315

Meteorological Data

Also required in the SWOE scene generation procedure are meteorological data, including data on surface weather, atmospheric conditions, and solar loading. Meteorological parameters used in the procedure are listed in Table 1.

Six weeks of 1-min meteorological data were collected using several field stations (Hahn 1994) during the SWOE/JT&E field program at YPG during the period 15 March 1993 to 30 April 1993; hourly data were summarized and are stored in the information base and are used by the component models. These data represent the winter-to-spring desert transition weather conditions for the months of March and April 1993 (Hahn 1994).

3-D Geometric Vegetation (Plant) Data

Three-dimensional geometric model data are representations of predominant 3-D vegetative features in the area such as trees and bushes. There were no urban features (i.e., buildings) within the area. Data to support these representations include geographic location, height, species, stem and branching structures, foliage sizes, and densities.

There are four dominant tree/bush types within the SWOE/JT&E database area. In their general order of dominance, the tree/bush types (species) are creosote bush (*Larrea tridentata*), brittlebush (*Encelia farinose*), yellow palo-verde (*Cercidium microphyllum*), and saguaro cactus (*Cereus giganteus*). The creosote bushes were widely spaced, while the other vegetation types tended to cluster along the washes. Figures 8-11 are photographs of the four dominant vegetation types.

Data on vegetative stem, branching structures, and foliage characteristics on representative trees and bushes were characterized by surveying the geometry of the stems and branches. The measured plant foliage data are listed in Table 7. Generalizing these measurements for the same species of similar ages, 3-D geometric tree/bush models were developed to describe four different plant shapes. The four models and their descriptions are included in Table 8. These models were described and developed using Lindenmayer systems. The Lindenmayer system, termed L-system, is a string rewriting mechanism used commonly in describing the branching topology of the modeled plants (Prusinkiewicz 1989). Using the L-system descriptions, 3-D cylinder descriptions are produced for computer graphic rendering. Figures 12-15 illustrate the shapes of the four geometric plant models.

To obtain accurate plant locations within the designated ground imaging areas, 1,739 trees and bushes were surveyed within a range of approximately 500 m from the Thermal Infrared Processing System/Army Research Laboratory (TIPS/ARL) camera locations using techniques described in Hahn (1994).

Table 7
Plant Foliage Measurements

Name	Leaf Length cm	Leaf Width cm	Number of Leaves per Cluster	Number of Clusters per Stem
Creosote	1.0	0.5	50-100	23
Brittlebush	5.0	2.5	8	2
Paloverde	0.7	0.2	60	1
Catclaw	1.5	0.7	14-18	10-15
Saguaro	--	--	--	--

Table 8
Three-Dimensional Tree/Bush Models

Filename	Height, m	Description
creosote.wes	1.1	Creosote bush model
brittlebush.wes	0.5	Brittlebush and white burr sage model
palo_verde.wes	4.3	Yellow paloverde, blue paloverde, and catclaw model
saguaro.wes	7.0	Saguaro cactus model

The western and eastern imaging areas are shown in Figures 16 and 17, respectively. Survey information included plant species, geographic location, base elevation, height, and width. Figure 18 shows the locations of all 1,739 surveyed plant locations. Figures 19-27 show the spacing of the measured dominant plant species within the designated ground imaging areas.

Additional plant locations were generated extrapolating information obtained by random sampling and using the surveyed plant location data. Tables 9 and 10 list the data collected for the plant locations and characteristics. These data provided the information necessary to determine the average spacing characteristics for each plant species and general characteristics. This study revealed that typically the creosote bush and brittlebush populated the disturbed desert pavement areas, while the yellow paloverde, catclaw, saguaro cactus, and white burr sage thrived in or next to the wash areas. The interpreted locations generated depended on species density and proximity to wash areas, and a total of 25,213 locations were generated. Figure 28 depicts the plant-interpreted vegetation basal locations. The locations were then combined with the measured to form the final composite basal location file. Figure 29 shows the composite vegetation basal locations.

A model scale value was assigned to each designated tree/bush location by dividing the measured height by the height of its corresponding geometric

Table 9
Plant Characterization Measurements in a Secondary Wash

Type	Distance m	Bearing deg	Height m	Width m
CR	17.7	25	1.4	1.6
CR	14.4	28	1.2	1.6
CR	17.4	50	0.7	1.2
CR	14.1	59	0.7	0.9
CR	11.3	65	0.4	0.6
CR	7.0	68	1.1	1.5
CR	7.1	99	0.9	1.6
CR	20.0	115	1.2	1.1
CR	9.1	138	0.7	0.9
CR	8.4	143	0.9	1.2
CR	9.4	145	0.5	0.6
CR	17.4	157	0.5	1.0
CR	19.4	162	1.0	1.3
CR	16.4	181	1.0	1.5
CR	12.7	183	0.6	1.0
CR	19.9	188	0.6	1.3
CR	10.2	197	1.2	1.6
CR	9.5	199	1.1	1.4
CR	4.8	202	0.9	1.6
CR	13.8	200	0.5	0.6
CR	17.1	204	0.6	1.2
CR	10.3	221	1.3	1.6
CR	20.0	224	1.0	1.6
CR	15.8	232	0.5	0.9
CR	16.1	231	0.8	0.9
CR	15.1	232	0.9	1.1
CR	4.9	250	0.7	0.8

(Continued)

Note:
CR - creosote bush
WB - white burr sage

Distance and Bearing data referenced to WES survey station. (See Hahn 1994).

Table 9 (Concluded)				
Type	Distance m	Bearing deg	Height m	Width m
CR	2.4	276	1.1	1.6
CR	10.1	266	0.4	1.0
CR	17.0	280	0.4	0.7
CR	12.6	283	0.9	1.1
CR	19.7	301	1.0	1.3
CR	18.8	308	1.2	1.6
CR	10.1	350	0.8	1.3
CR	9.4	4	1.1	1.5
WB	9.9	5	0.7	1.1
CR	19.8	7	0.6	1.0
CR	18.2	10	1.1	1.3
CR	2.7	14	0.7	1.0

plant model. This scale value was then applied to the geometric plant model. This technique allows scaling a representative geometric plant model to the height of each measured tree/bush. For each interpreted plant location within the 1.78- by 0.58-km area, the tree/bush basal elevation, tree/bush model, and model scale were assigned. An example of the tree/bush location file is in Table 11.

Several 3-D color graphical plots were generated using ray-tracing techniques and the SWOE information base discussed above. These representations are depicted in Figures 30-34.

Texture Data

Texture data were developed for the scene generation procedure that corresponded to a single vegetation type at a specific time of day. Each set of parameters corresponded to a single background terrain type at a specific time of day. The texture parameters were used by the SWOE rendering software system for application of thermal texture to terrain areas for which a single mean temperature is calculated.

Data needed to generate the synthetic textures were collected by the WES field team during a diurnal measurement period on 18 March 1993 under clear-sky weather conditions. Calibrated imagery of two surface types, desert pavements and bare soil, were obtained at multiple times in 3- to 5- and 8- to

Table 10
Plant Characterization Measurements on Disturbed Desert Pavement

Type	Bearing deg	Distance m	Height m	Width m
CR	10	17.6	0.8	1.3
CR	10	18.5	0.6	0.7
CR	22	10.7	0.7	1.4
CR	25	18.2	0.5	0.8
CR	30	15.4	0.8	1.4
CR	34	16.7	0.5	0.9
CR	35	19.2	1.0	1.4
CR	43	5.9	0.2	0.3
CR	69	9.1	0.7	0.9
CR	70	11.3	0.9	1.3
CR	72	14.8	0.8	1.1
CR	74	14.3	1.0	1.5
CR	75	14.8	0.9	1.6
CR	101	8.3	0.9	1.4
CR	112	10.5	0.9	1.3
CR	127	3.4	0.3	0.5
CR	131	8.6	1.1	1.7
CR	149	15.6	1.2	1.6
CR	149	16.2	0.8	0.9
CC	158	17.6	1.3	1.7
CR	156	17.9	0.7	1.1
CR	176	15.6	0.9	1.3
CR	180	7.0	0.6	0.7
CR	180	7.4	0.7	0.9
CR	196	15.8	0.8	1.3
CR	198	15.1	1.1	1.6

(Continued)

Note:
CR - creosote bush
CC - catclaw tree

Distance and Bearing data referenced to WES survey station (See Hahn 1994).

Table 10 (Concluded)				
Type	Bearing deg	Distance m	Height m	Width m
CR	210	15.6	0.9	1.7
CR	213	9.9	0.9	2.0
CR	220	10.3	0.9	1.6
CR	259	6.3	0.9	1.4
CR	267	2.5	0.7	1.2
CR	263	13.0	0.9	1.6
CR	271	17.2	1.0	1.3
CR	285	18.0	0.8	1.5
CR	295	19.3	0.8	1.1
CR	315	6.6	1.2	2.7
CR	330	15.6	0.5	0.9
CR	354	9.4	1.3	2.7

12-µm wave bands. Correlation length and standard deviation data were calculated from these imagery, and 24 separate synthetic texture parameters were calculated. Texture parameters measured for Yuma terrain types are listed in Table 12.[1]

Terrain Parameters

In addition to the digital terrain data, a wide range of data defining the physical, thermal, and spectral attributes of each landscape unit is required for the SWOE scene generation procedure. These parameters are listed in Table 1. Complete descriptions of these attributes, as well as estimates of their value for various vegetation and soil types, can be found in Balick, Link, and Scoggins (1981); Smith et al. (1981); Dornbusch (1990); Hummel et al. (1991); Jones (1991); and Jordan (1991). Suggested physical parameters for the study area are contained in Appendix B.

[1] External Memorandum, 29 March 1993, Bruce Sabol, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Table 11
Example Tree/Bush Locations for YPG, AZ

X-Coordinate (Latitude)	Y-Coordinate (Longitude)	Plant Base Elevation	Model	Model Scale Factor
32.967571	-114.262016	245.3	creosote	1.545
32.967564	-114.262032	245.3	creosote	1.364
32.967560	-114.262032	244.8	creosote	0.545
32.967598	-114.262054	245.1	creosote	1.273
32.967602	-114.262093	245.1	creosote	1.636
32.967548	-114.262115	245.1	creosote	1.455
32.967537	-114.262039	245.4	creosote	0.818
32.967510	-114.262070	246.1	creosote	1.727
32.967510	-114.262085	246.0	creosote	1.000
32.967503	-114.262077	245.2	creosote	1.545
32.967518	-114.262131	245.2	creosote	1.636
32.967445	-114.262085	245.0	creosote	1.455
32.967430	-114.262138	245.0	brittlebush	1.800
32.967464	-114.262146	245.9	creosote	1.636
32.967487	-114.262222	245.3	creosote	1.000
32.967468	-114.262222	245.0	creosote	1.364
32.967571	-114.262207	245.4	creosote	0.455
32.967461	-114.262291	246.2	creosote	2.273
32.967457	-114.262306	245.9	brittlebush	1.800
32.967445	-114.262299	246.9	brittlebush	1.600

Table 12
Measured Texture Parameters for Yuma Terrain Types

Time (mm/dd/yy) (hh:mm:ss)	Terrain Types											
	Desert Pavement						Bare Soil (washes and road)					
	3- to 5-μm Wave Bands			8- to 12-μm Wave Bands			3- to 5-μm Wave Bands			8- to 12-μm Wave Bands		
	Mean	SD	CL	Mean	SD	CL	Mean	SD	CL	Mean	SD	CL
03/18/93 00:00:00	17.8	0.4	0.11	17.8	0.4	0.26	17.4	0.4	0.10	17.2	0.3	0.16
03/18/93 06:00:00	12.9	0.4	0.14	15.7	0.4	0.49	12.1	0.5	0.20	14.7	0.4	0.31
03/18/93 09:00:00	33.0	1.5	0.29	26.8	1.2	0.21	28.5	1.9	0.20	24.7	1.4	0.13
03/18/93 12:00:00	50.0	2.1	0.16	39.4	1.7	0.12	45.3	2.0	0.17	36.7	1.7	0.17
03/18/93 15:00:00	49.0	1.7	0.16	40.4	1.3	0.11	48.4	1.4	0.11	40.2	1.2	0.09
03/18/93 18:00:00	32.5	1.0	0.26	28.2	0.8	0.48	31.8	1.2	0.52	27.6	0.8	0.20

Note:
(a) SD - standard deviation in apparent temperature (°C).
(b) CL - correlation length in meters.
(c) Range of resolution cell sizes of measured imagery.
Desert Pavement: 0.020 to 0.022 m
Bare Soil: 0.019 to 0.021 m

4 Summary

This report documents the methods developed for the environmental information base component of the SWOE/JT&E thermal infrared scene generation procedure. An environmental information base was designed and developed for a 1.78- by 0.57-km site at YPG, AZ.

Considerable effort was devoted to collecting and verifying geometric locations of individual tree/bush basal locations and their appropriate 3-D geometric models. An L-system description of these models allowed for a realistic rendering of the vegetation without the need for highly detailed measurements.

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Smith, J. A., Ranson, K. J., Nguyen, D., and Line, L. E. (1981). "Thermal vegetation canopy model studies," Technical Report EL-81-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

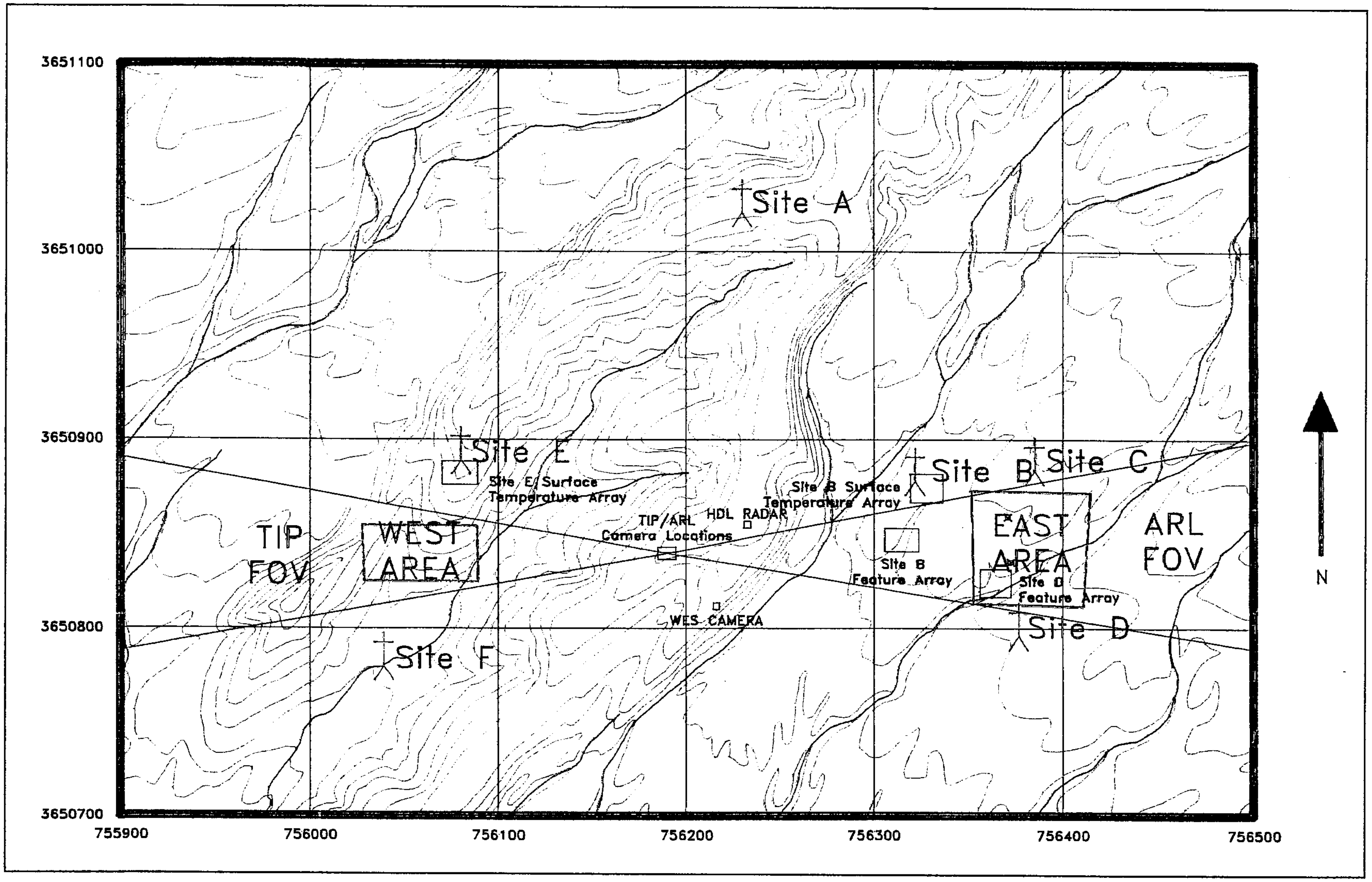

Figure 1. Vicinity map

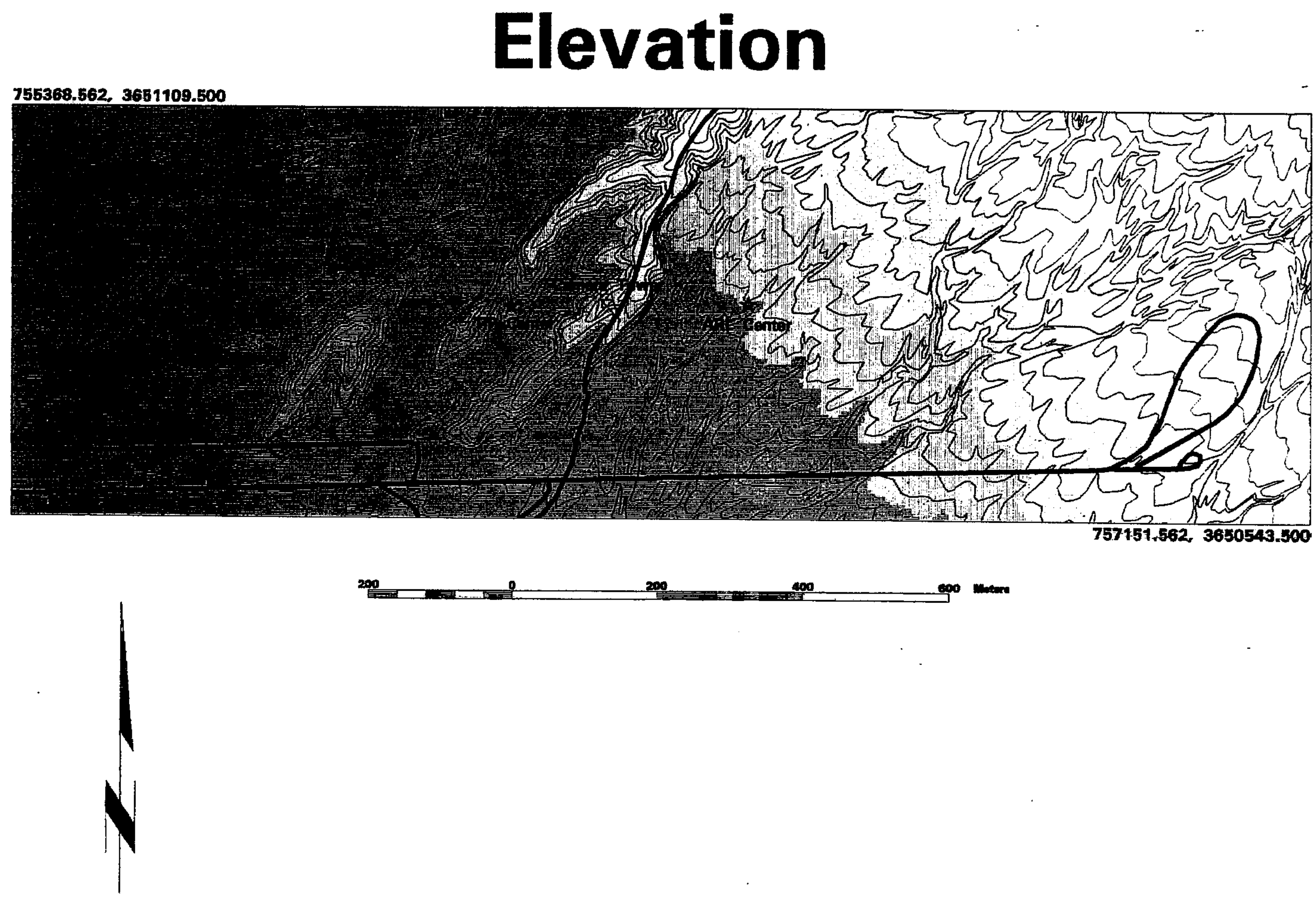

Figure 2. Topographic elevation, contour lines are at a 2-ft interval

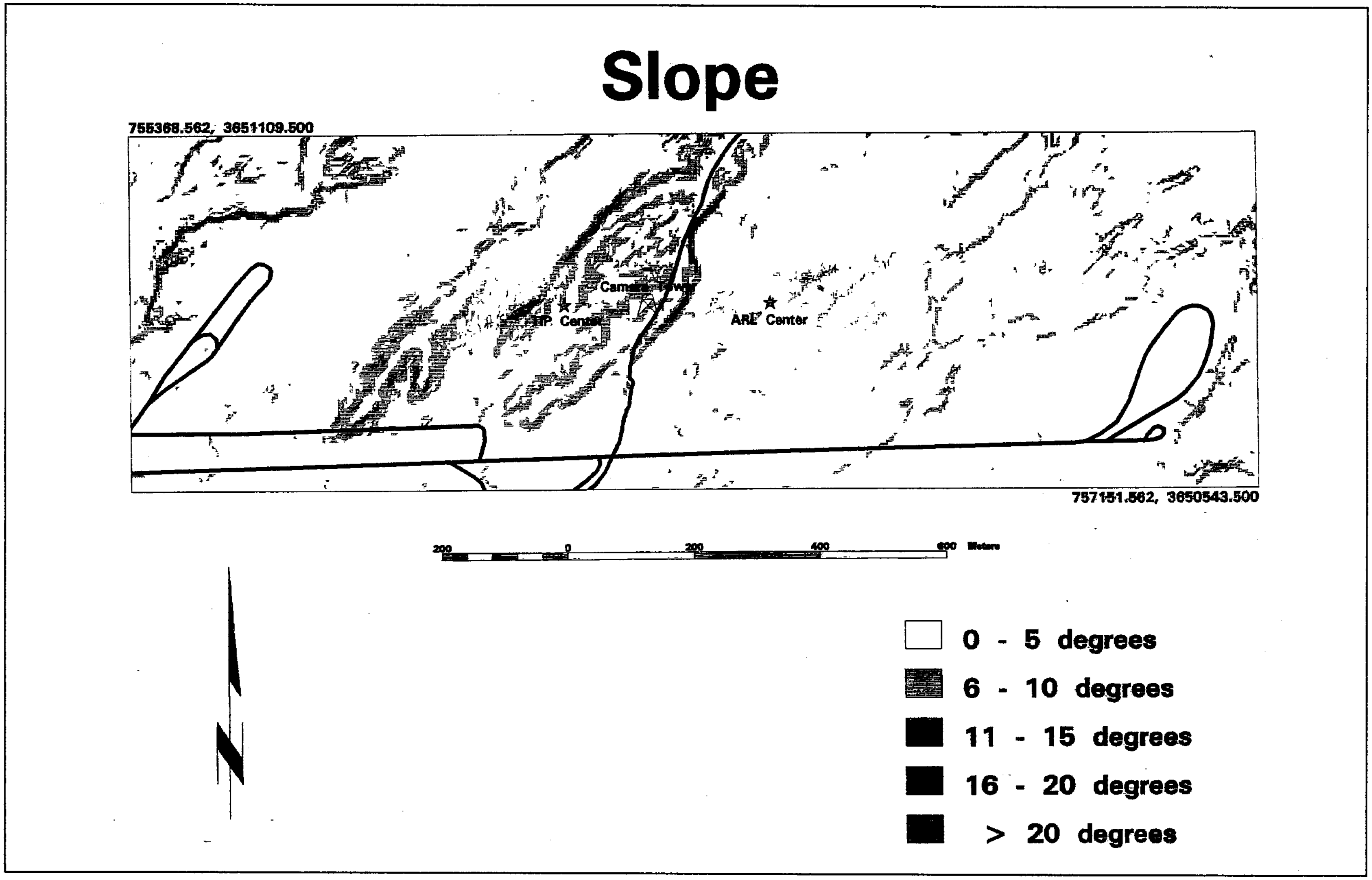

Figure 3. Topographic slope layer

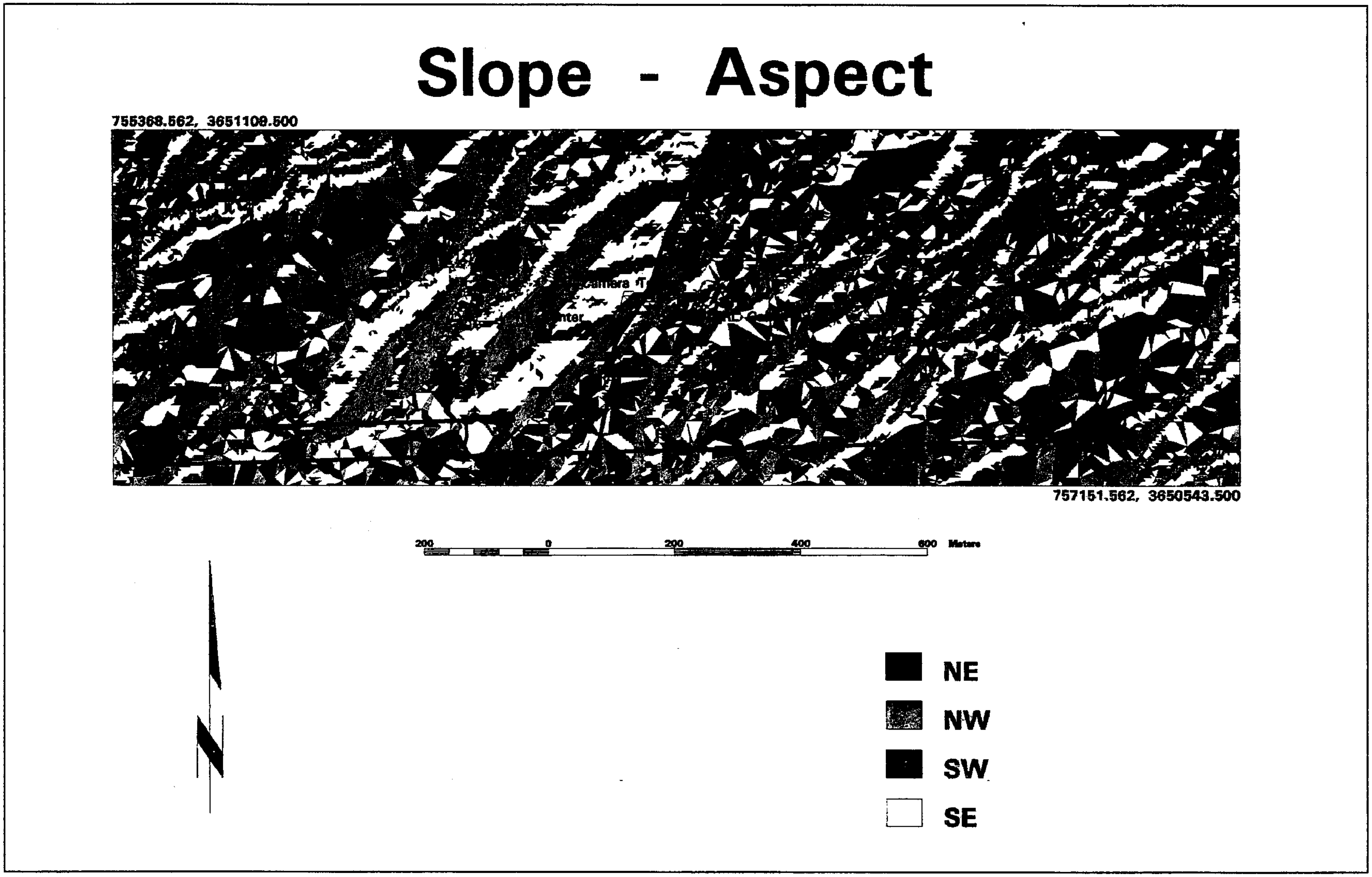

Figure 4. Topographic slope-aspect layer

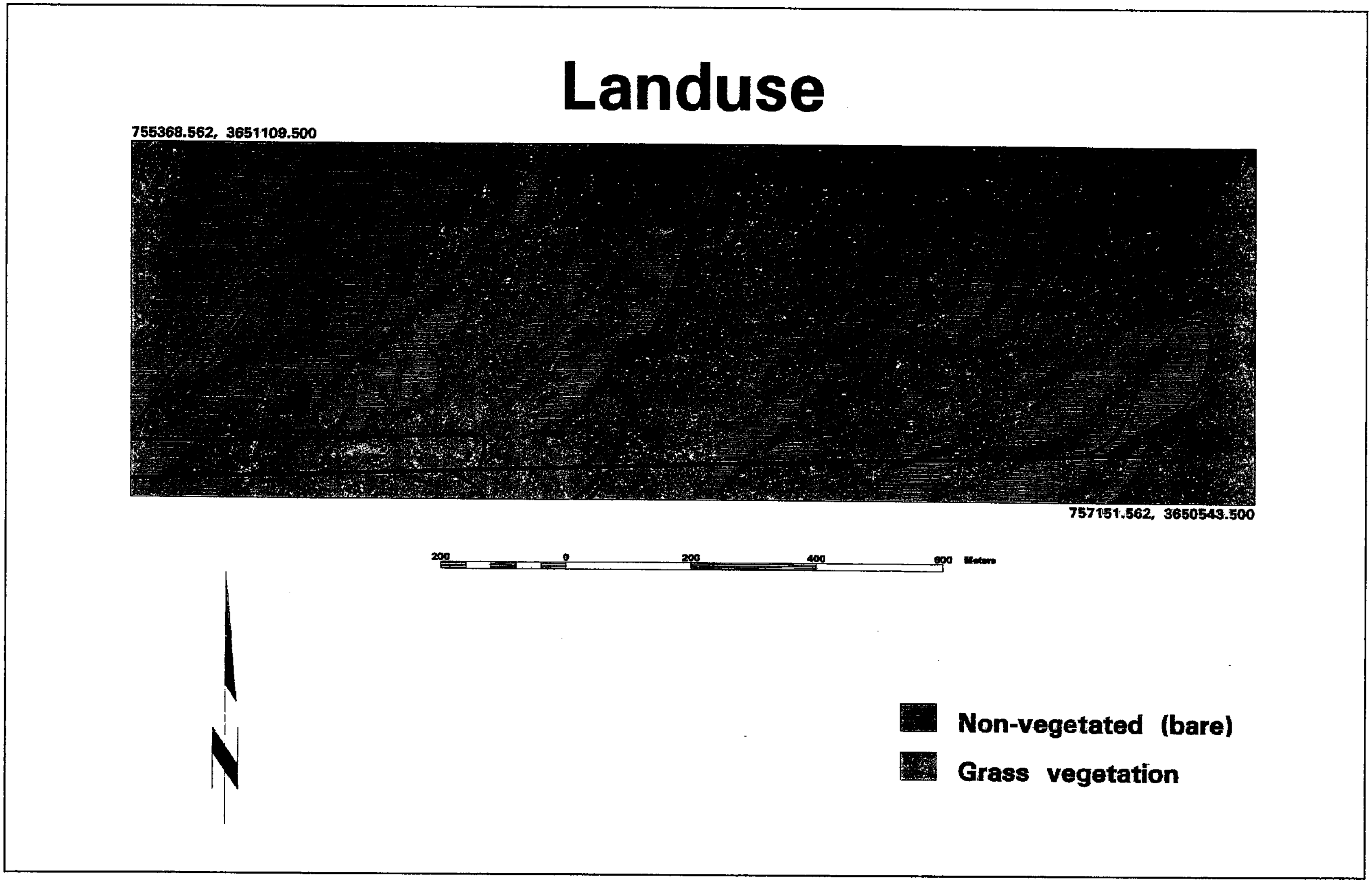

Figure 5. Vegetation/land use terrain layer

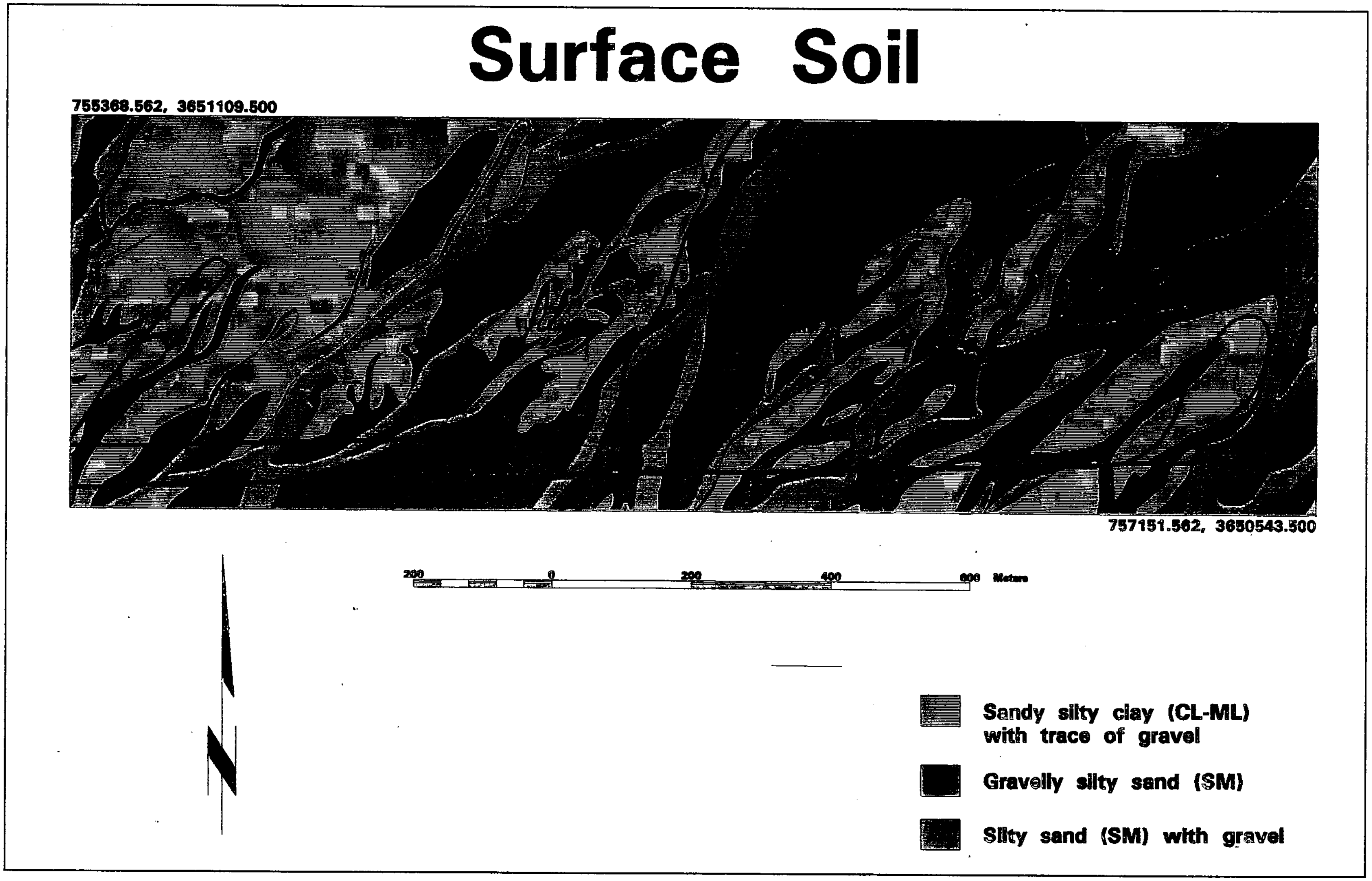

Figure 6. Surface soil terrain layer

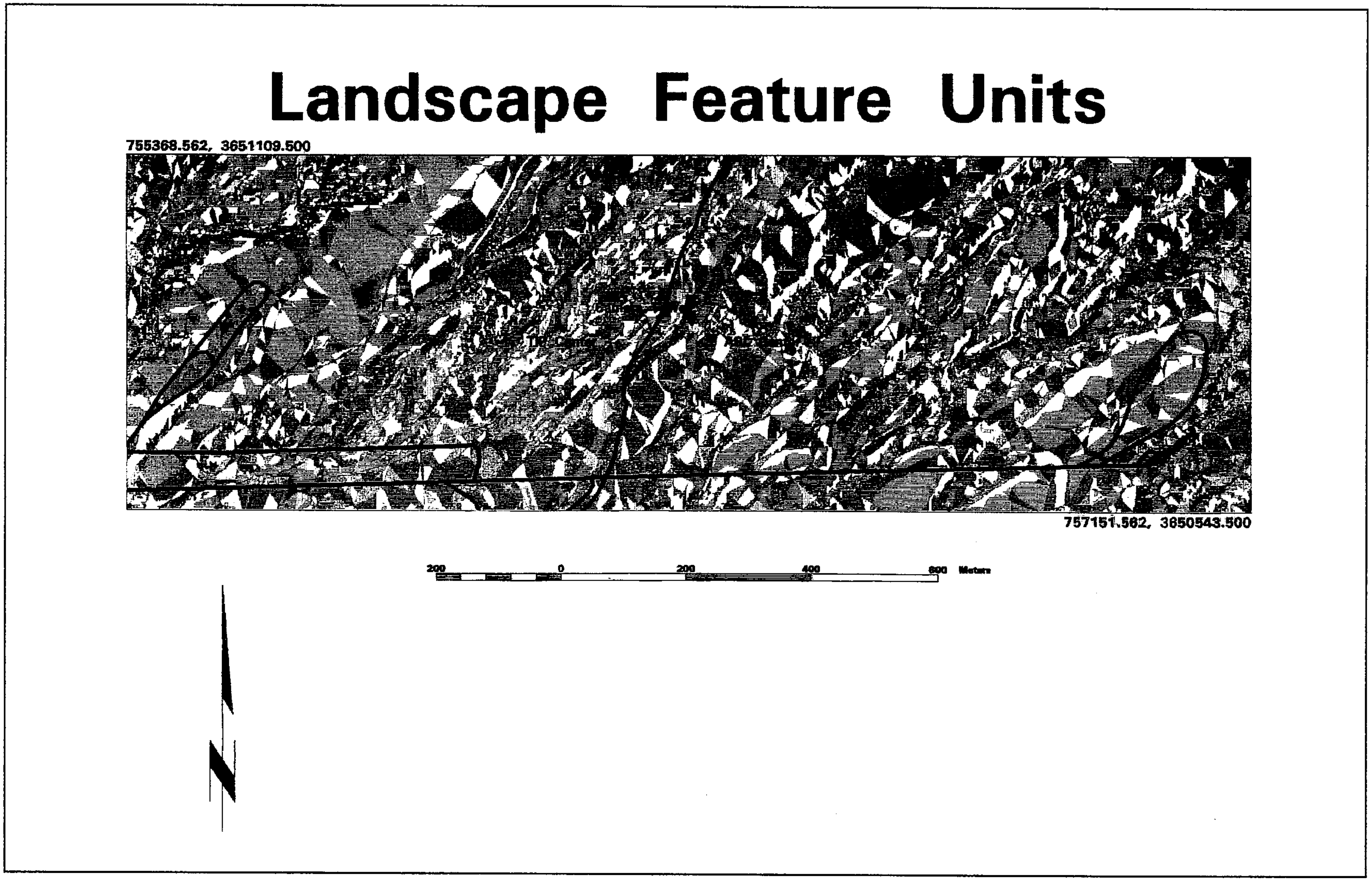

Figure 7. Composite landscape feature units layer (roads, tower, and imaging centers are also plotted on the map)

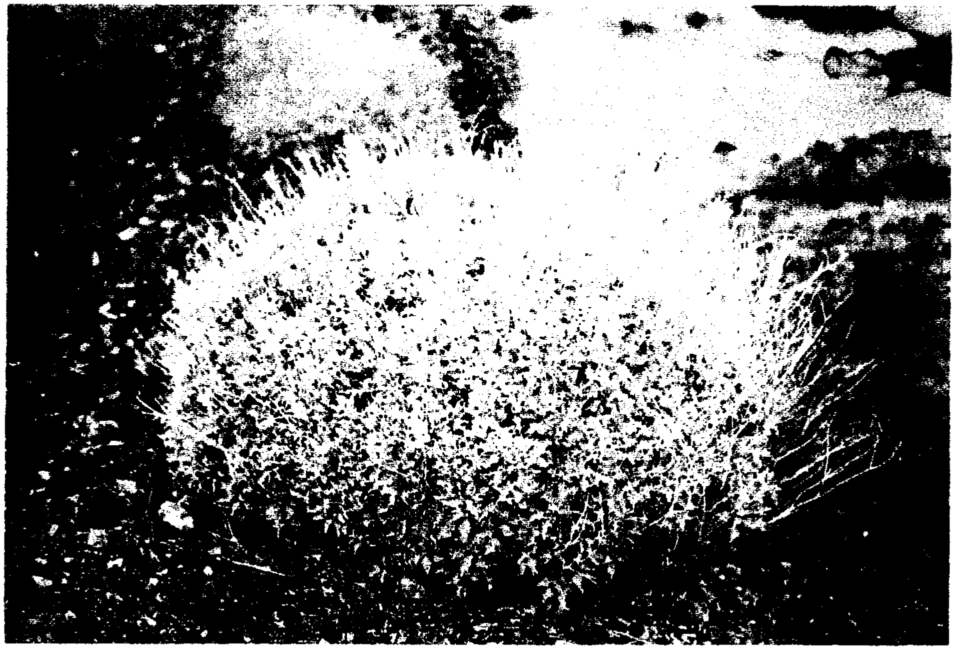

Figure 8. *Encelia farinose* (brittlebush)

Figure 9. *Larrea tridentata* (creosote bush)

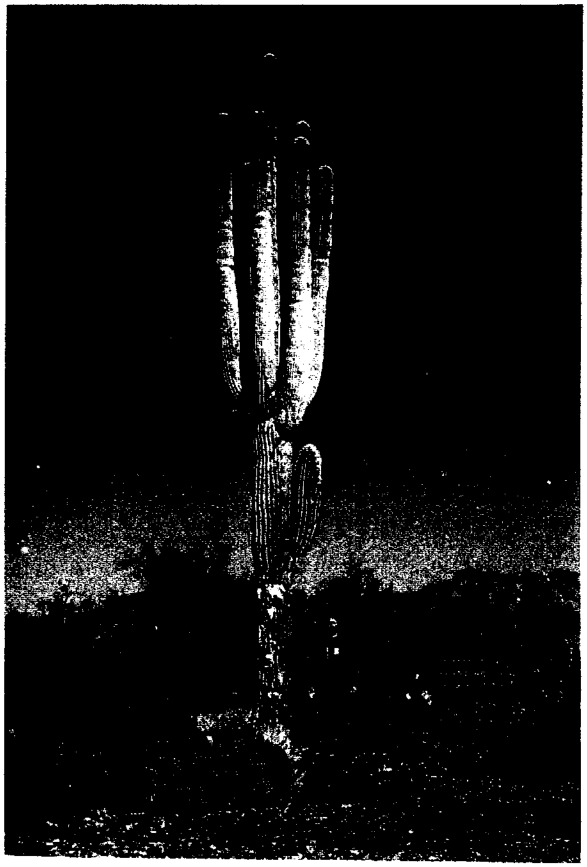

Figure 10. *Cereus giganteus* (saguaro cactus)

Figure 11. *Cercidium microphyllum* (yellow paloverde)

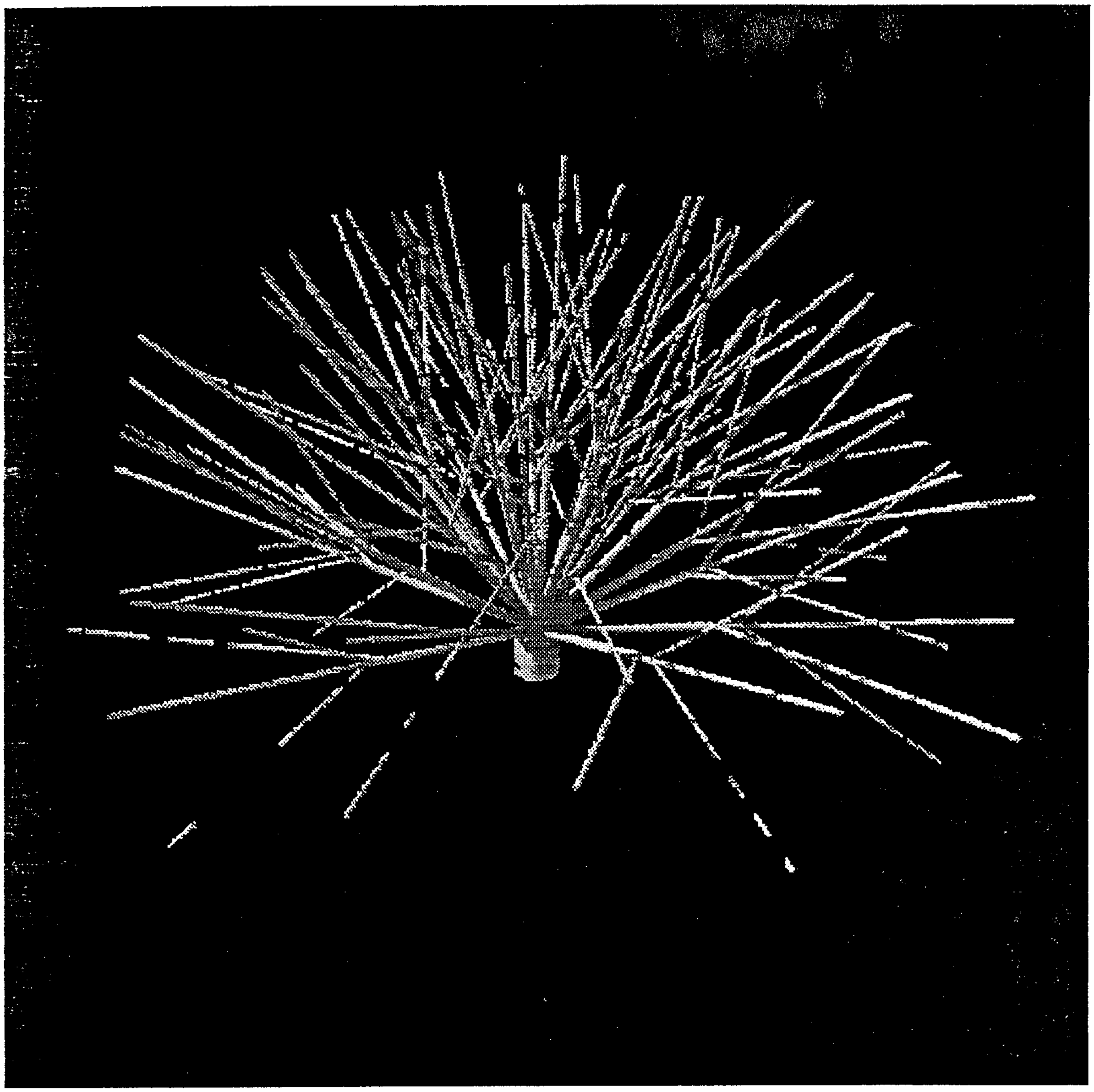

Figure 12. Brittlebush 3-D geometric model

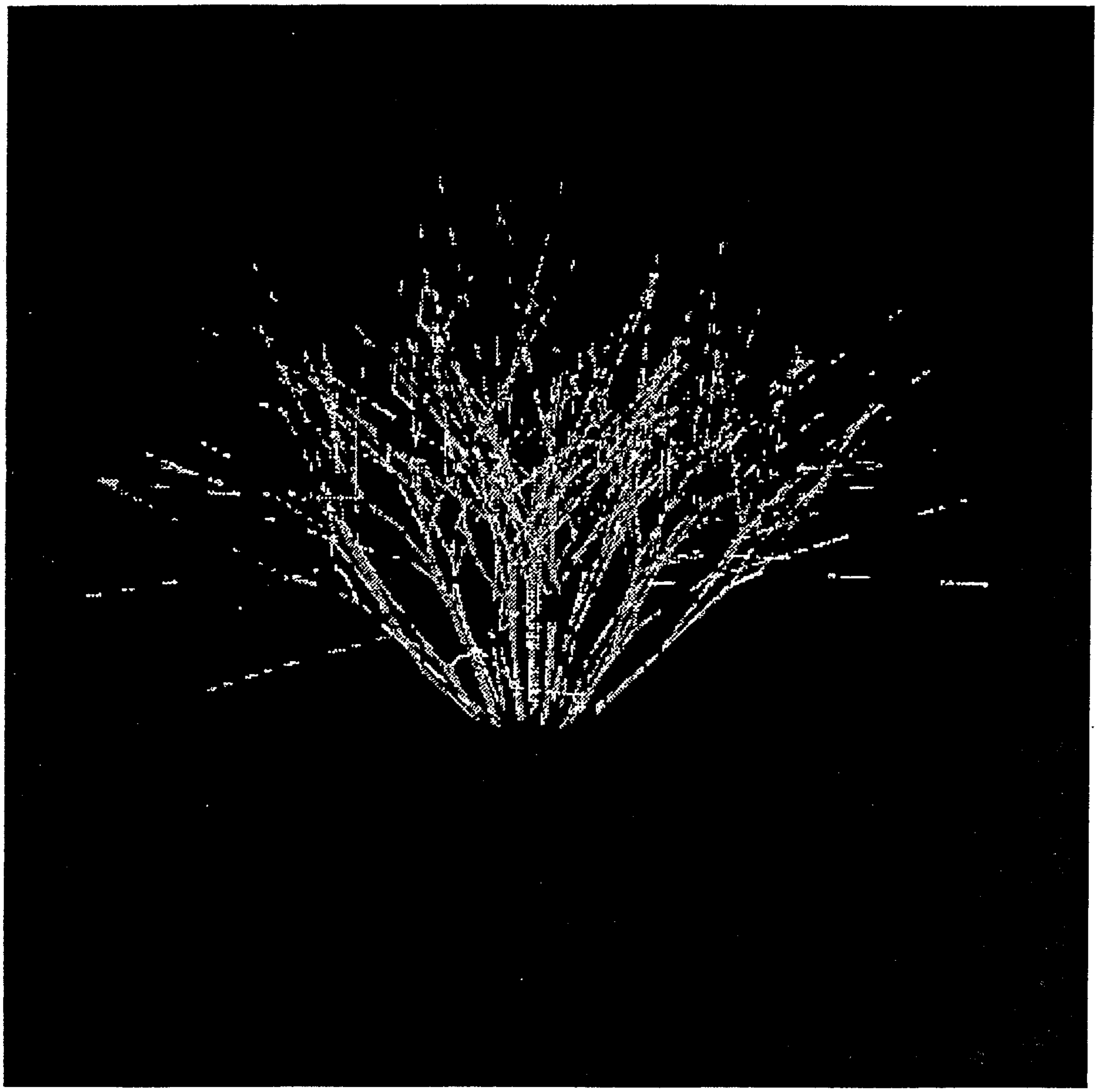

Figure 13. Creosote bush 3-D geometric model

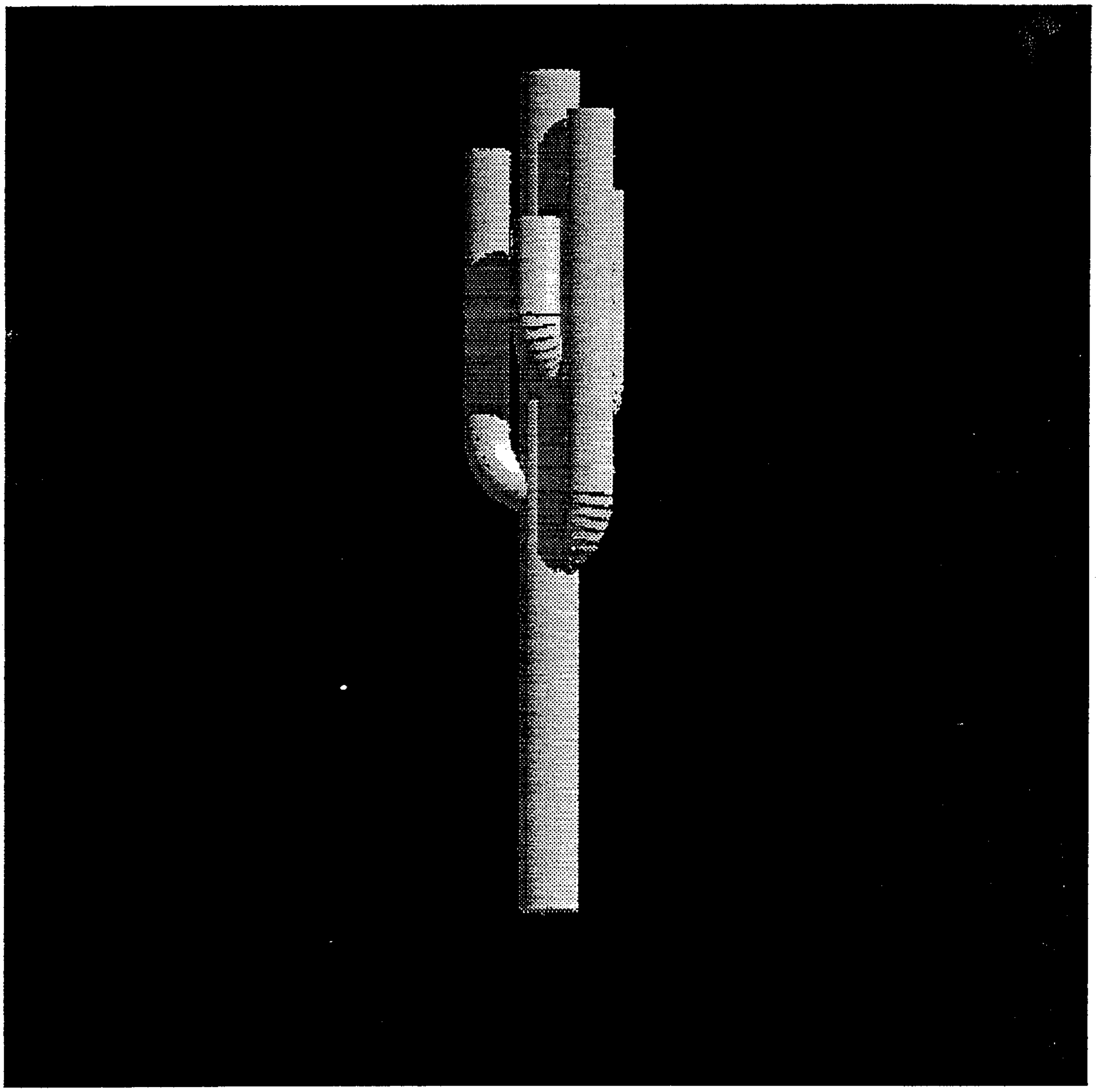

Figure 14. Saguaro cactus 3-D geometric model

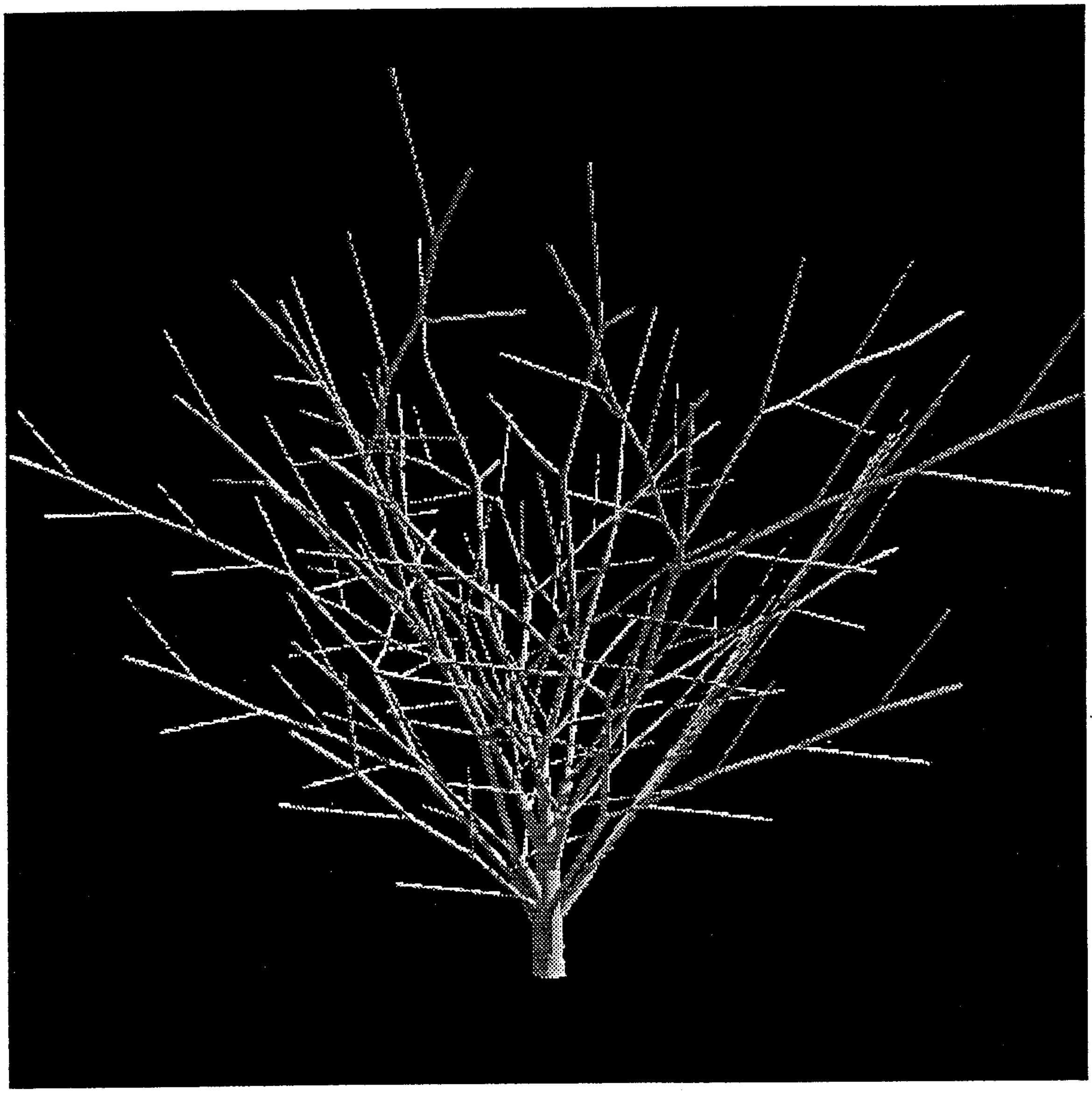

Figure 15. Paloverde 3-D geometric model

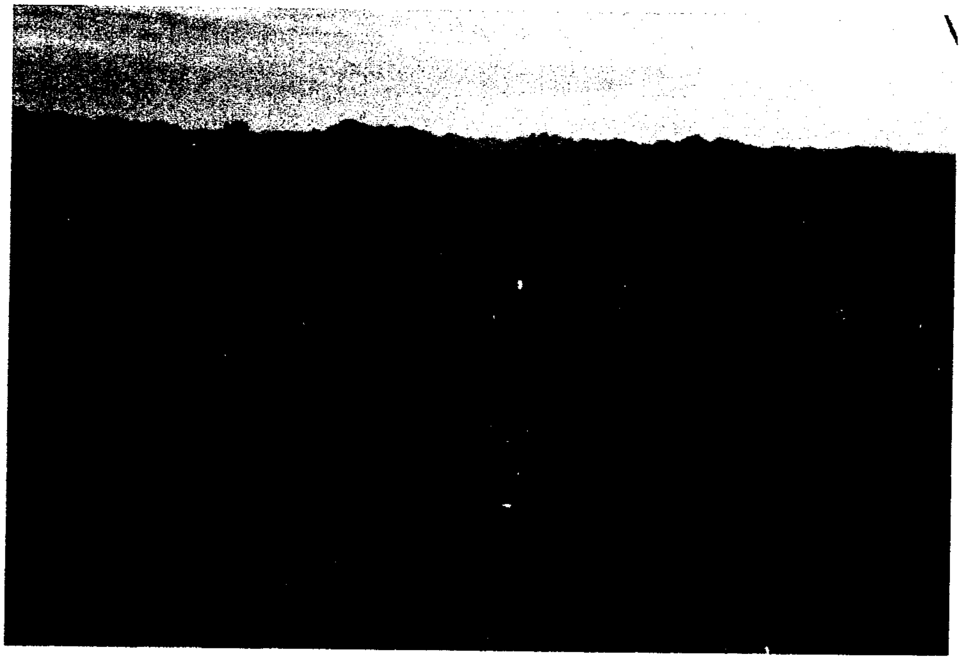

Figure 16. Photograph of eastern imaging area from sensor tower

Figure 17. Photograph of western imaging area from sensor tower

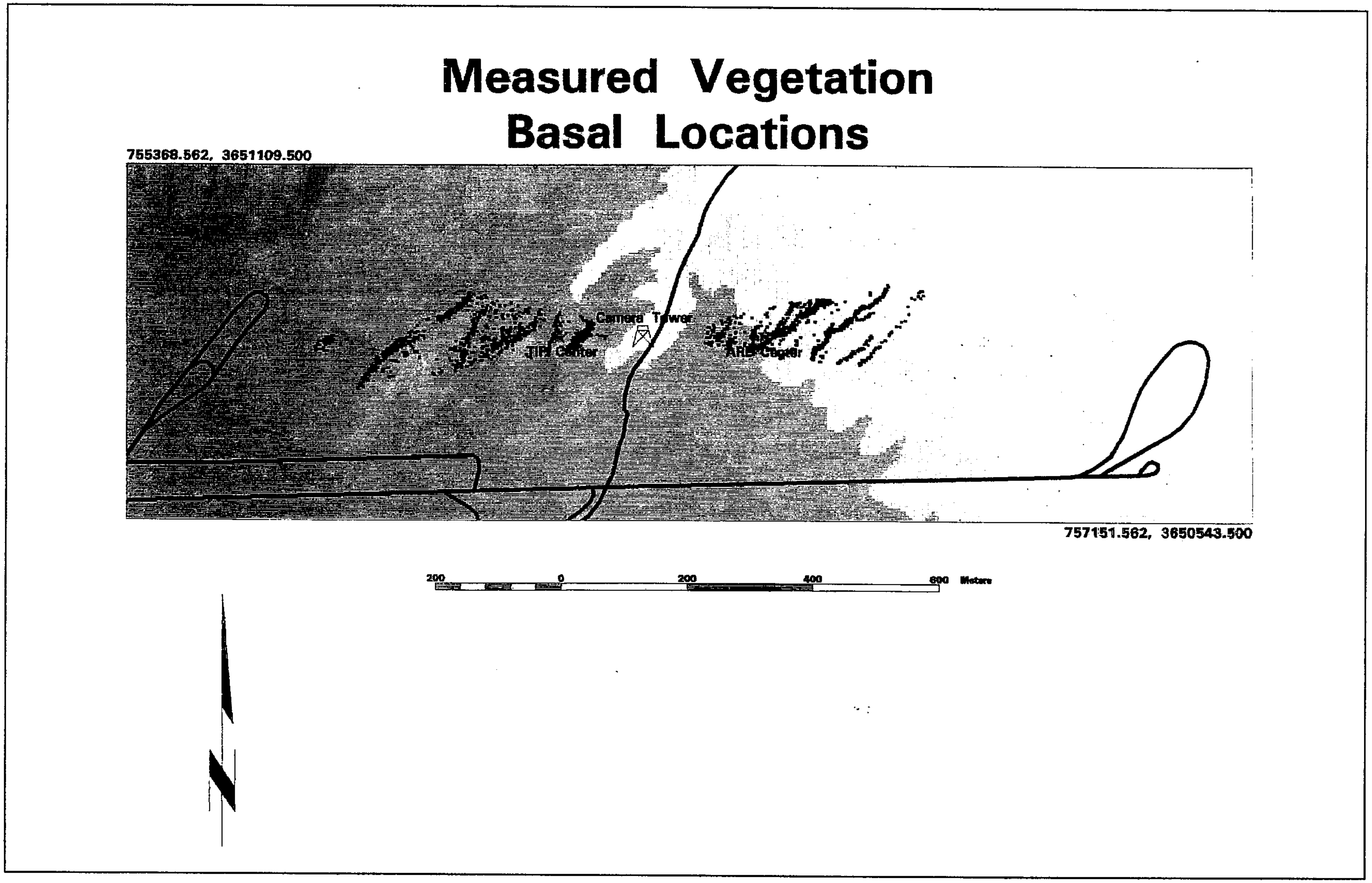

Figure 18. Measured vegetation basal locations

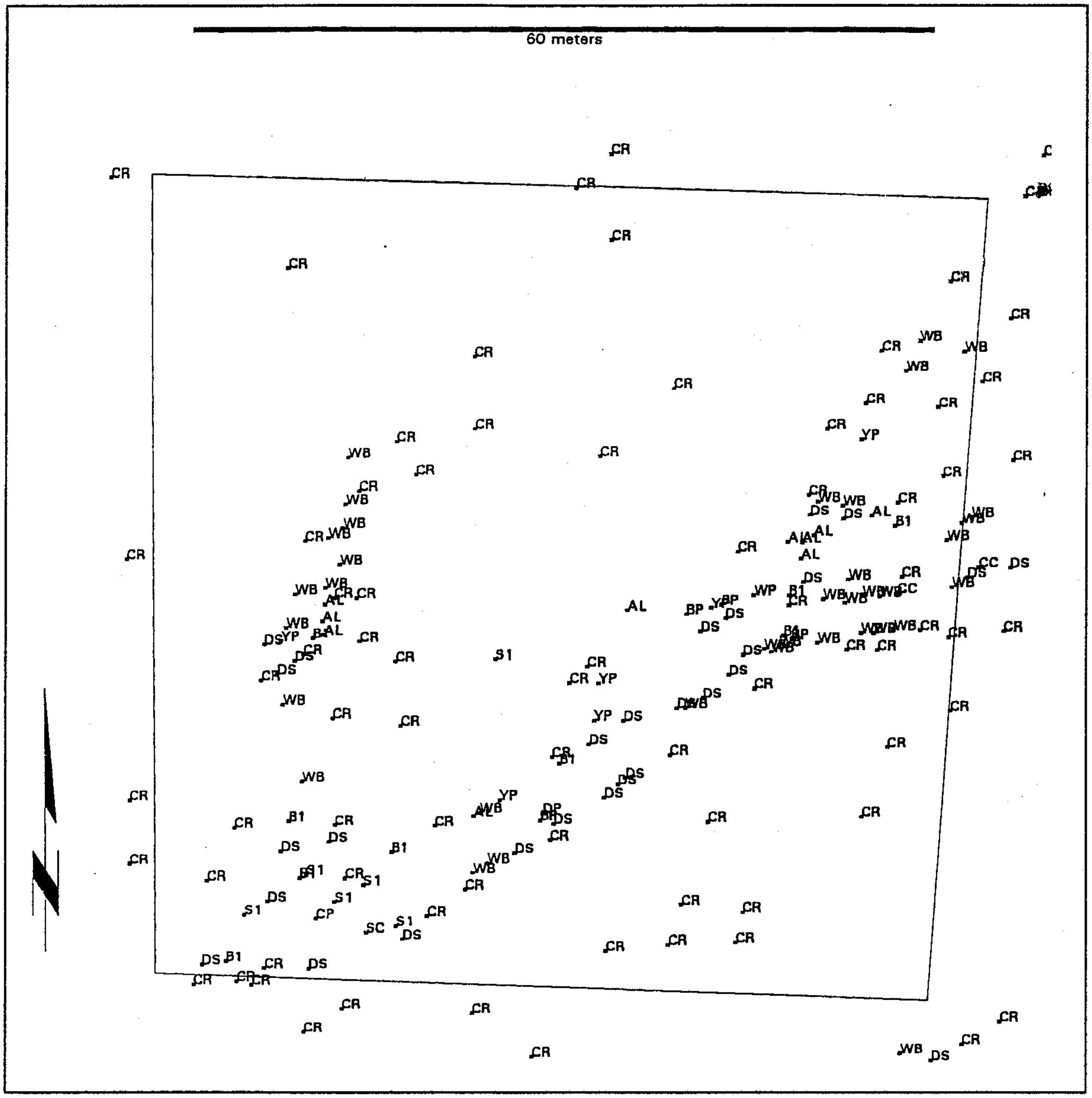

Figure 19. Spatial distribution of vegetation (trees and bushes) within eastern imaging area

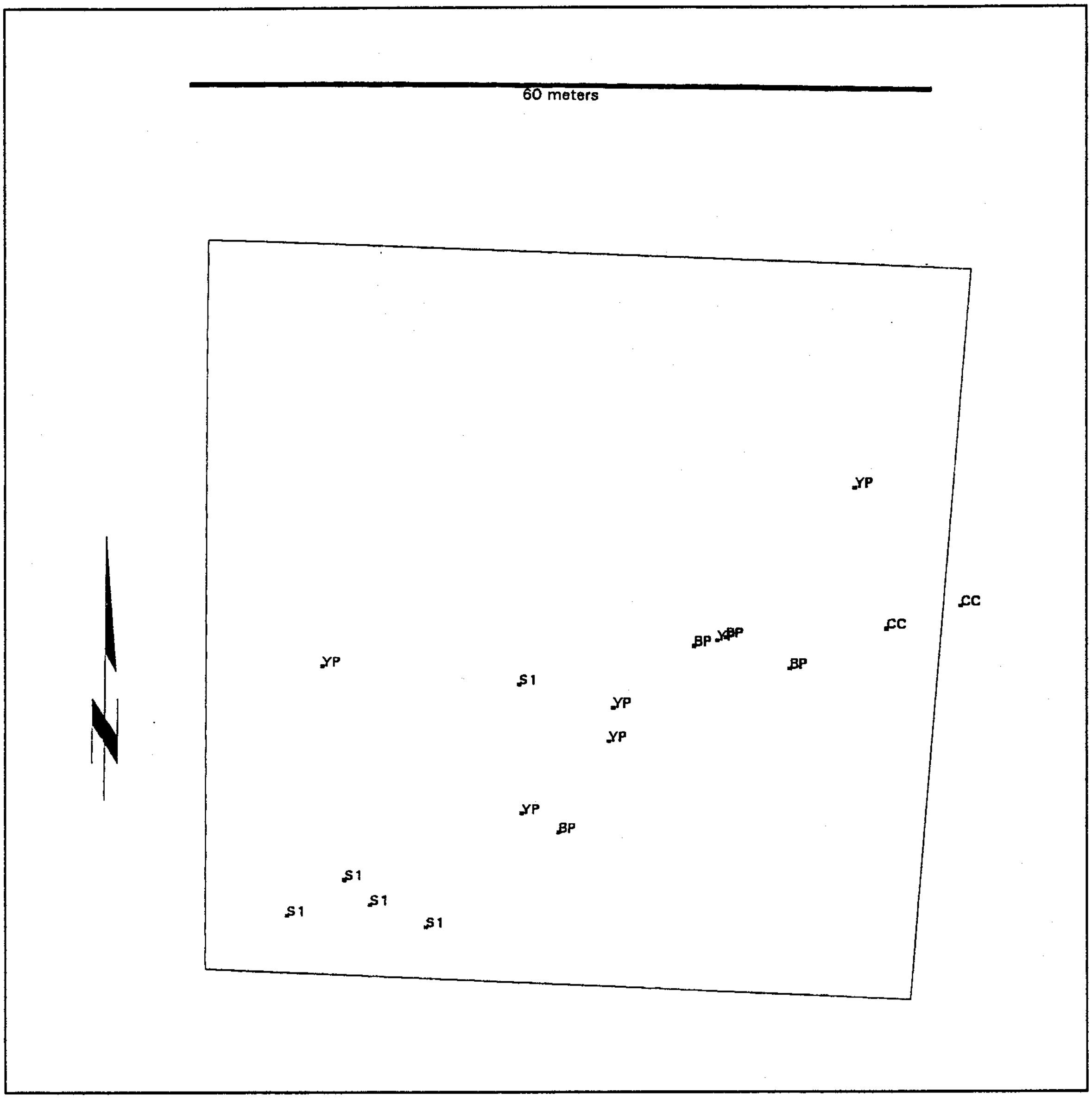

Figure 20. Spatial distribution of paloverde model within eastern imaging area

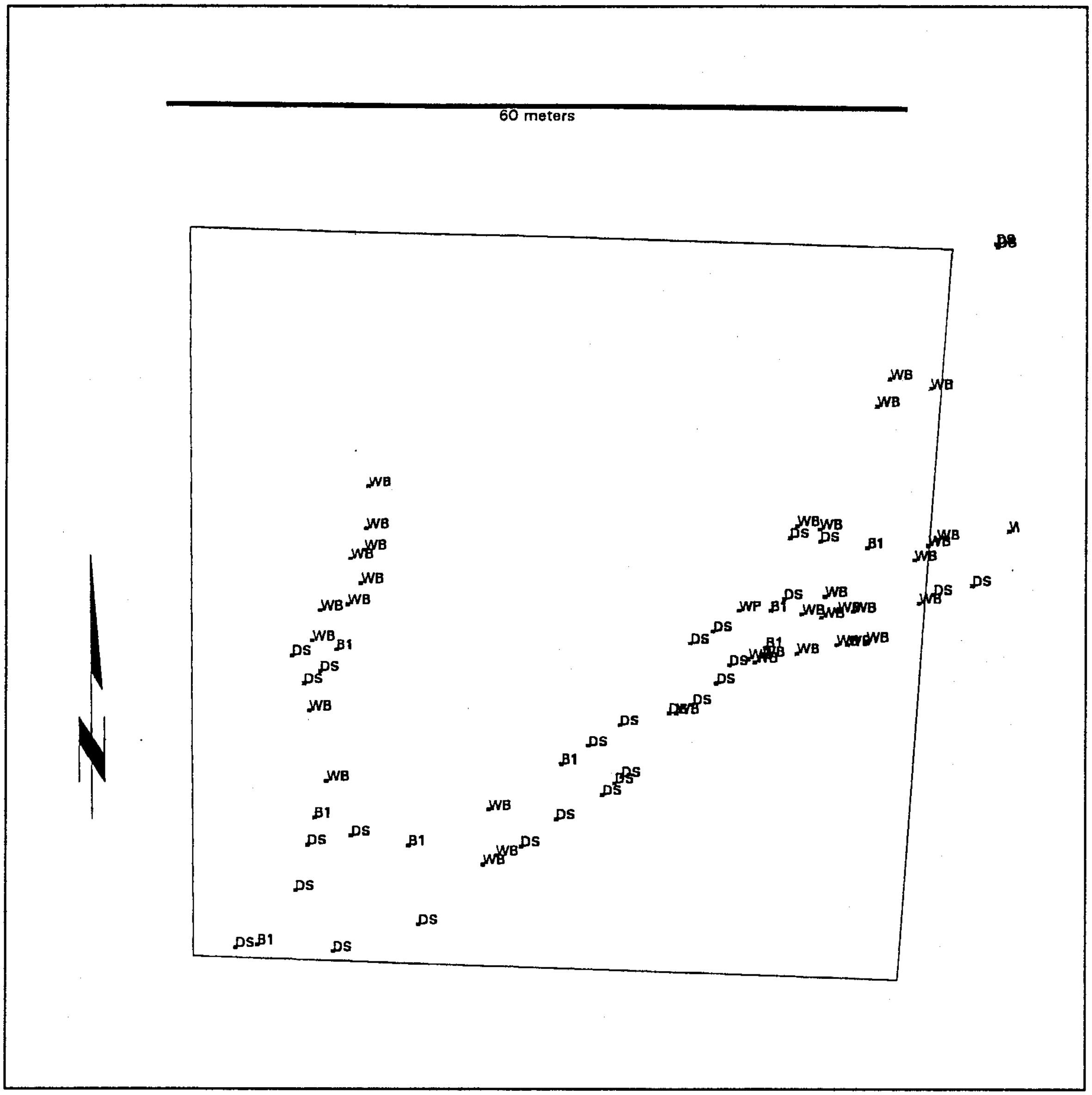

Figure 21. Spatial distribution of brittlebush model within eastern imaging area

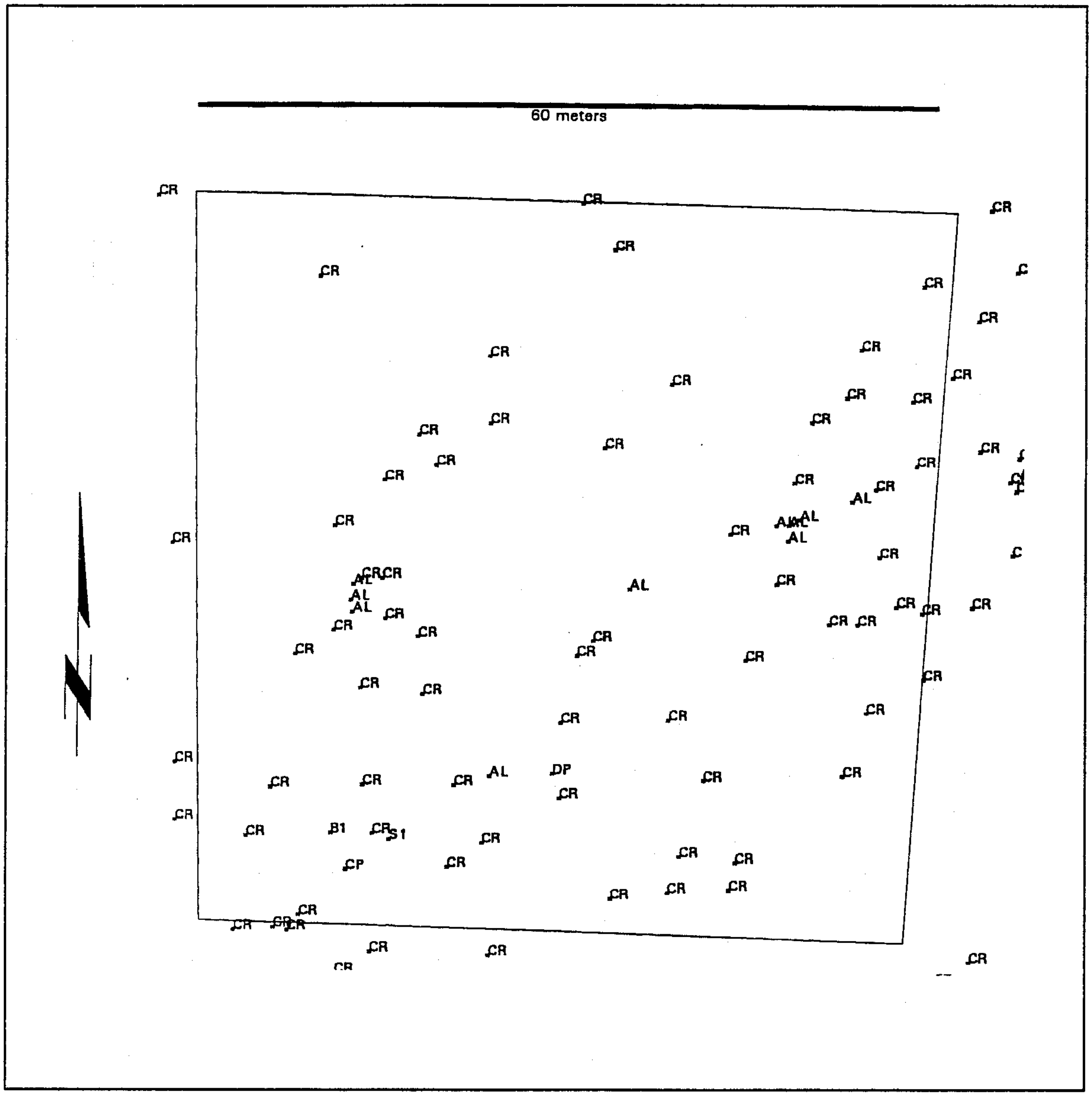

Figure 22. Spatial distribution of creosote model within eastern imaging area

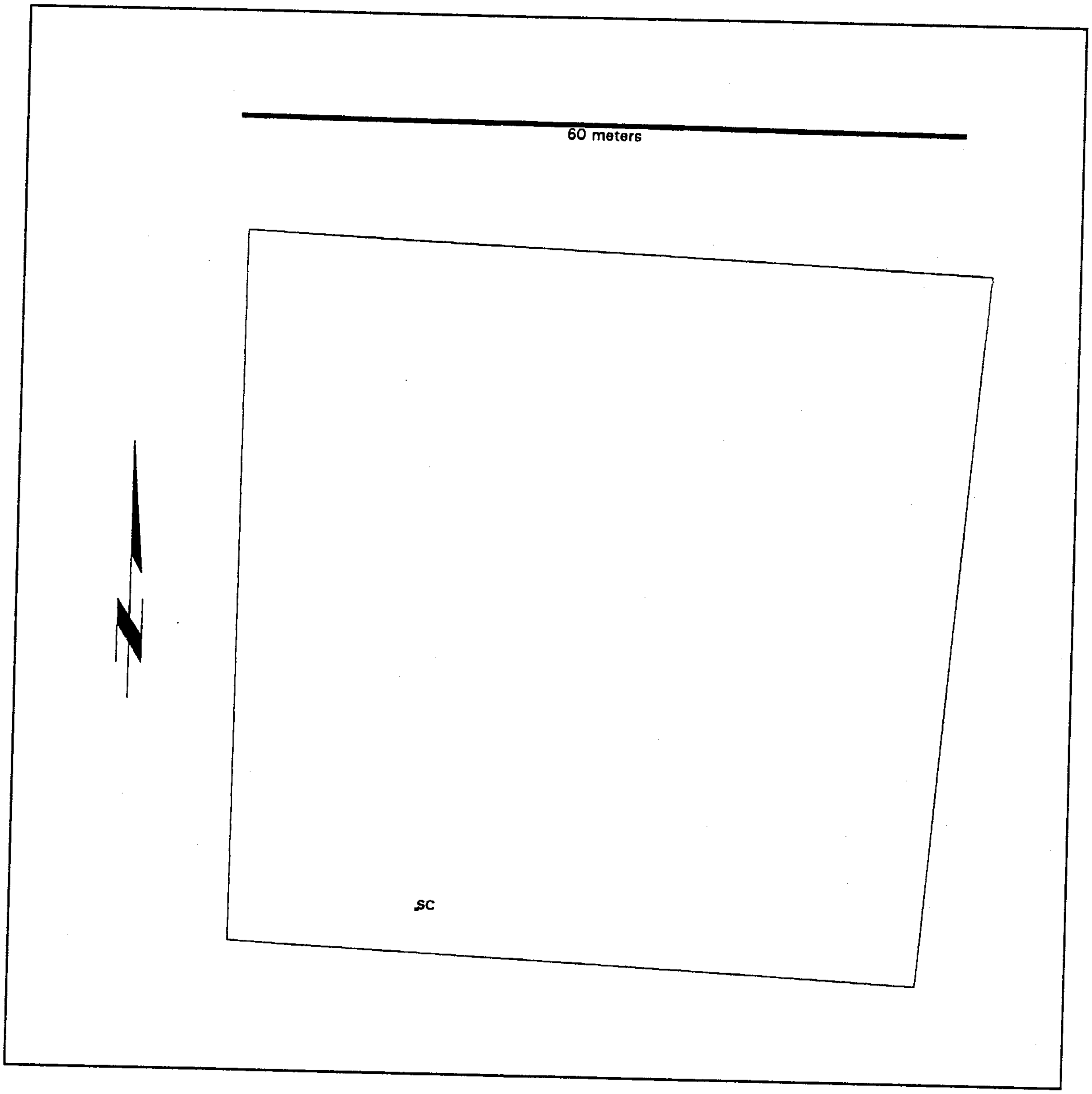

Figure 23. Spatial distribution of saguaro model within eastern imaging area

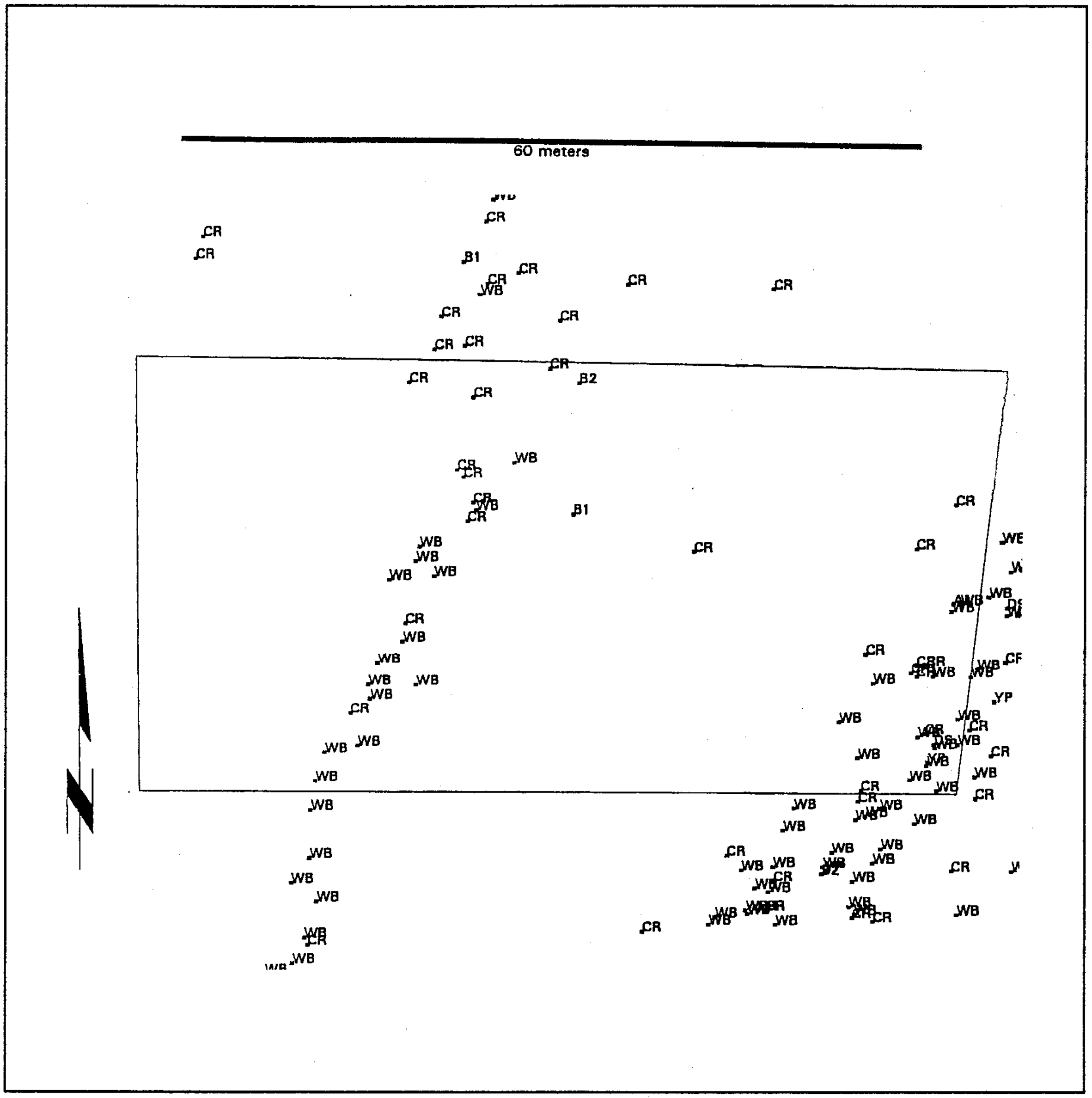

Figure 24. Spatial distribution of vegetation (trees and bushes) within western imaging area

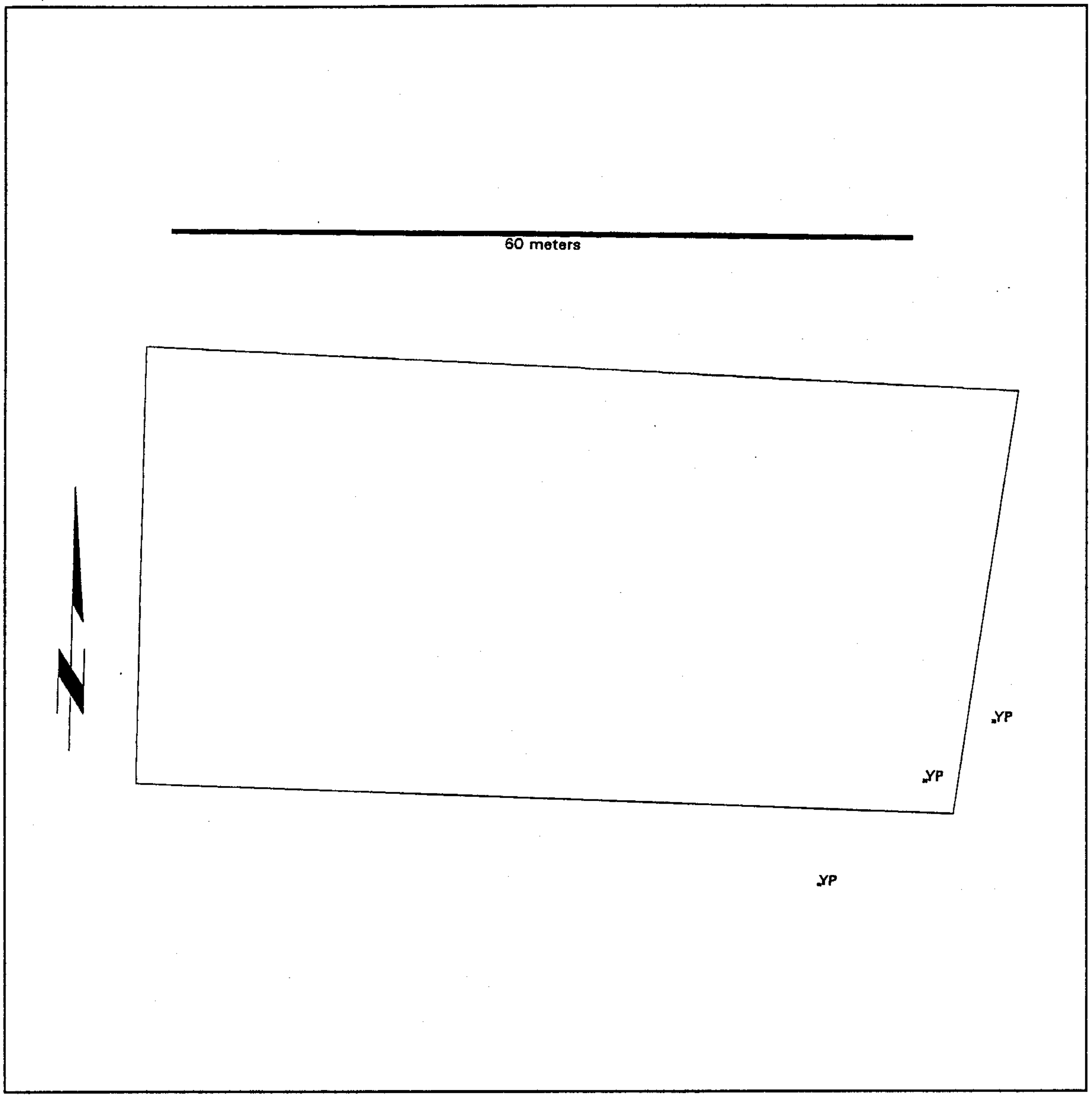

Figure 25. Spatial distribution of paloverde model within western imaging area

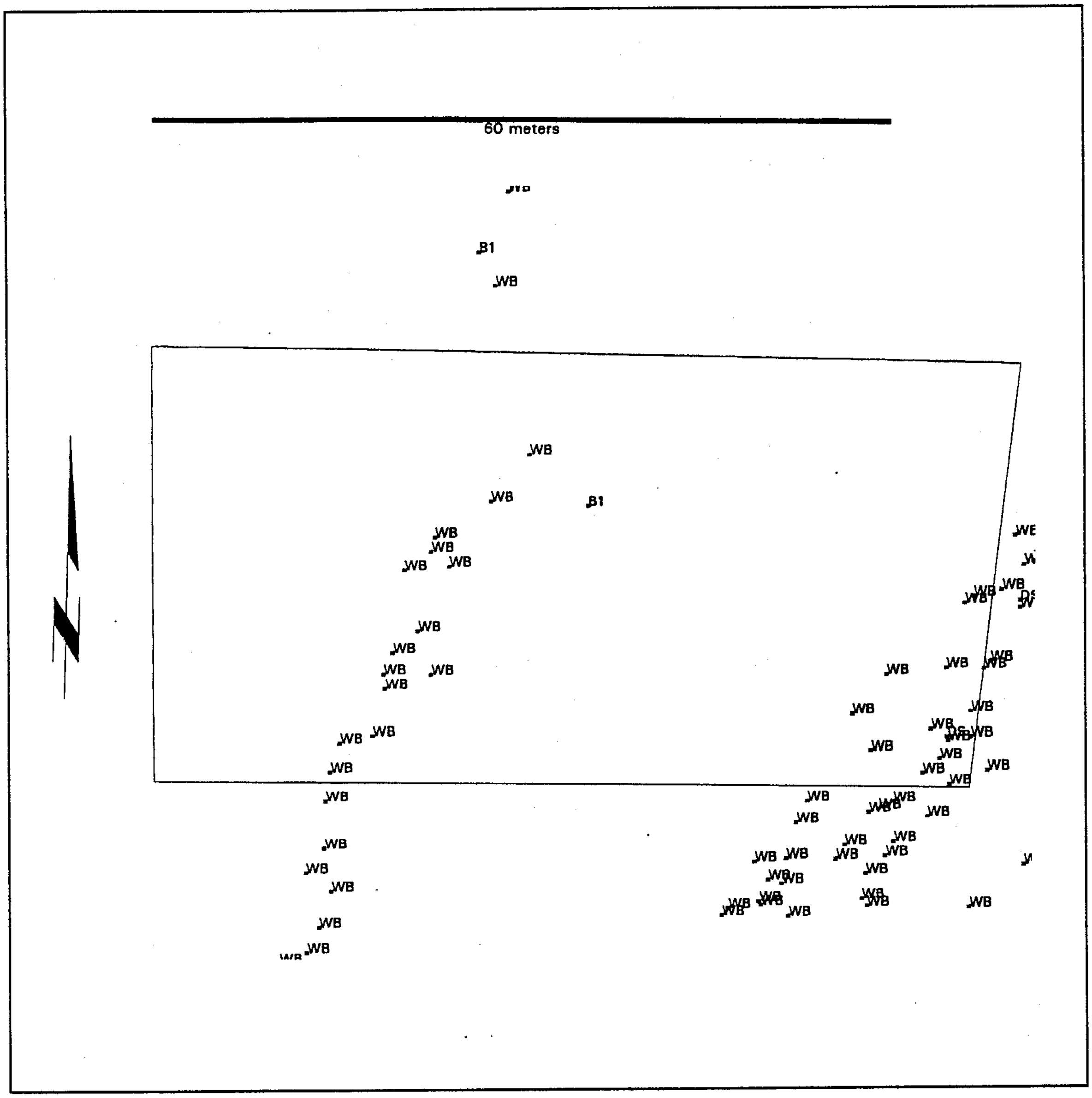

Figure 26. Spatial distribution of brittlebush model within western imaging area

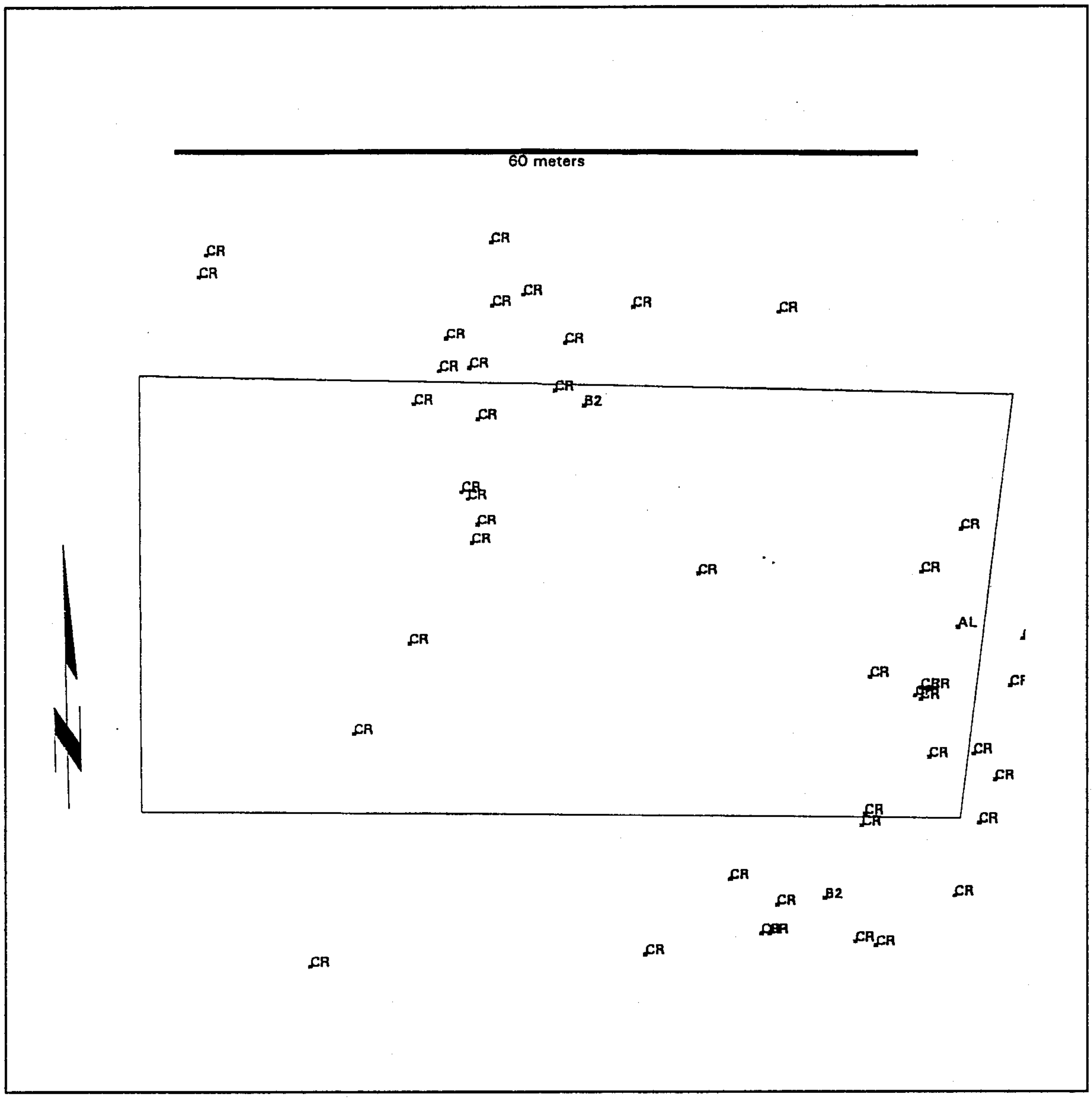

Figure 27. Spatial distribution of creosote model within western imaging area

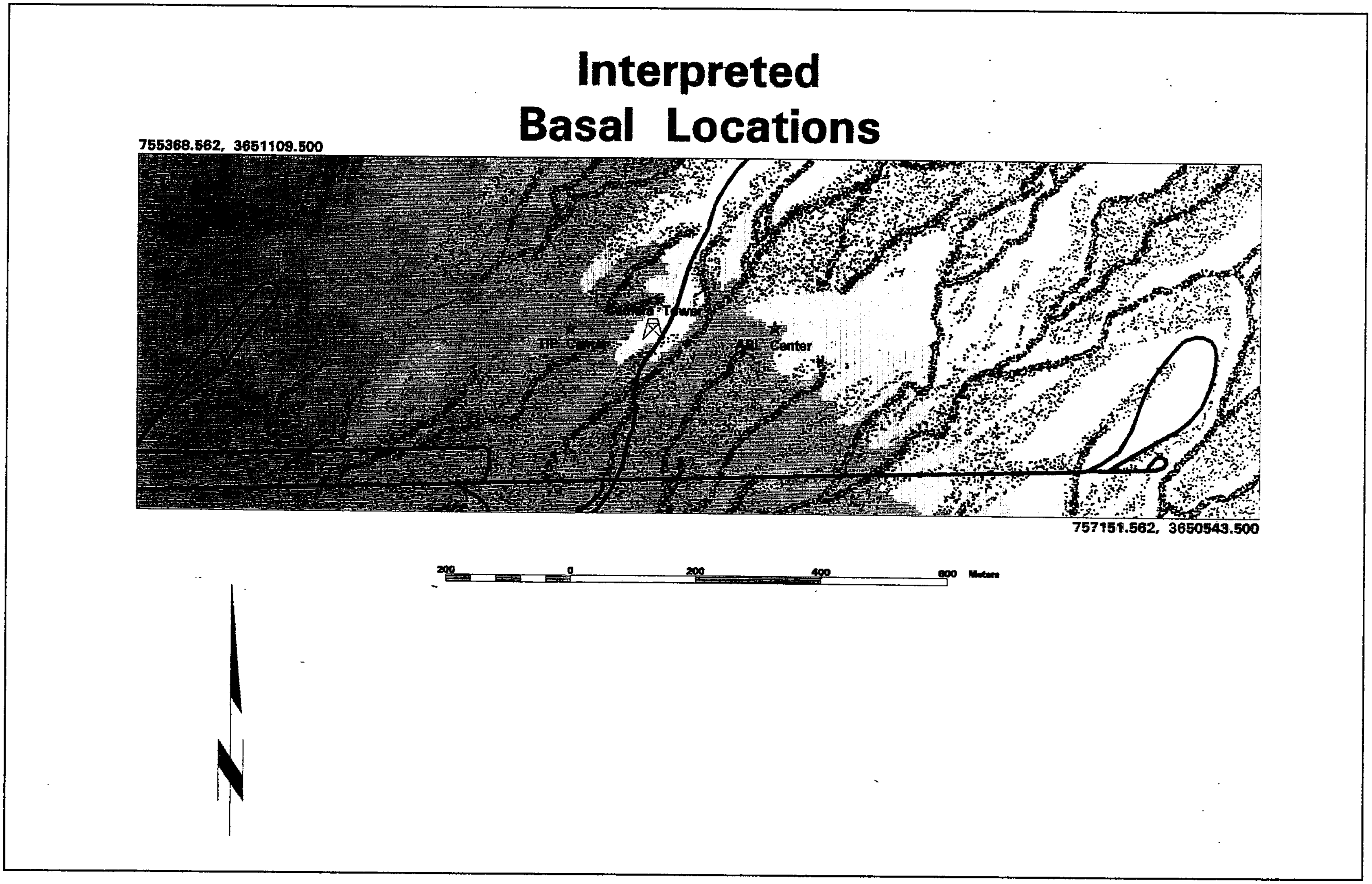

Figure 28. Interpreted vegetation basal locations

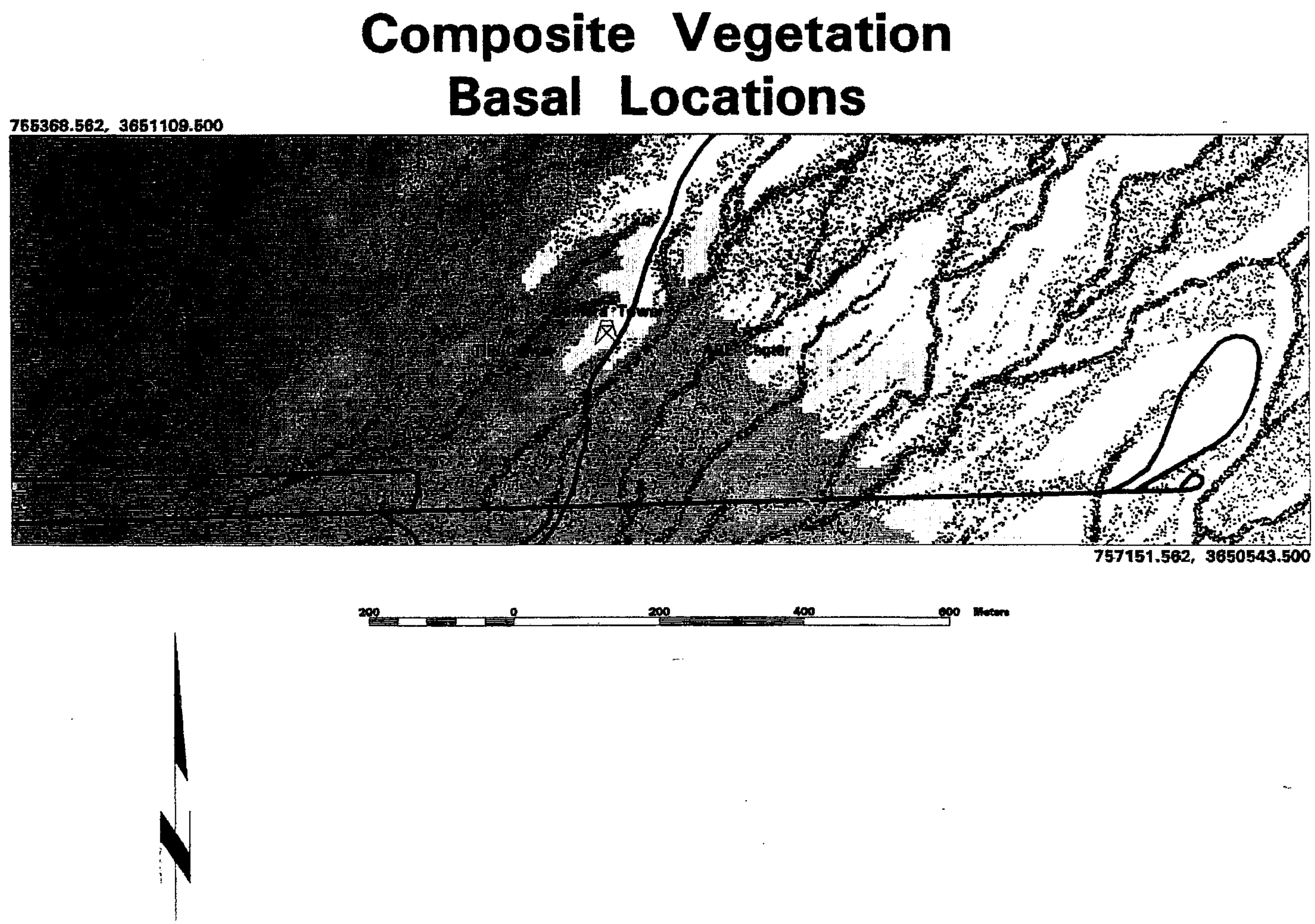

Figure 29. Interpreted and measured vegetation basal locations

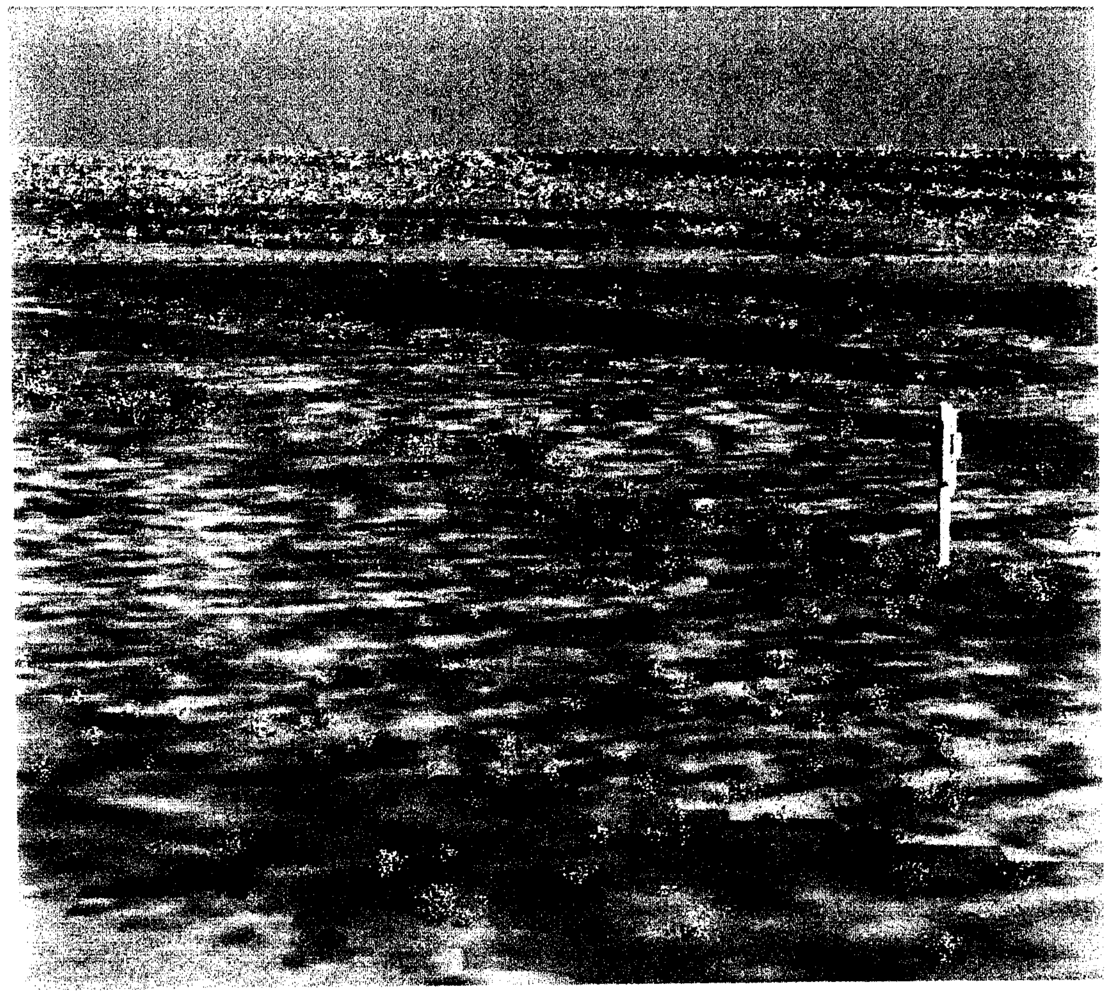

Figure 30. Three-dimensional graphical representation of information base facing toward the eastern imaging area

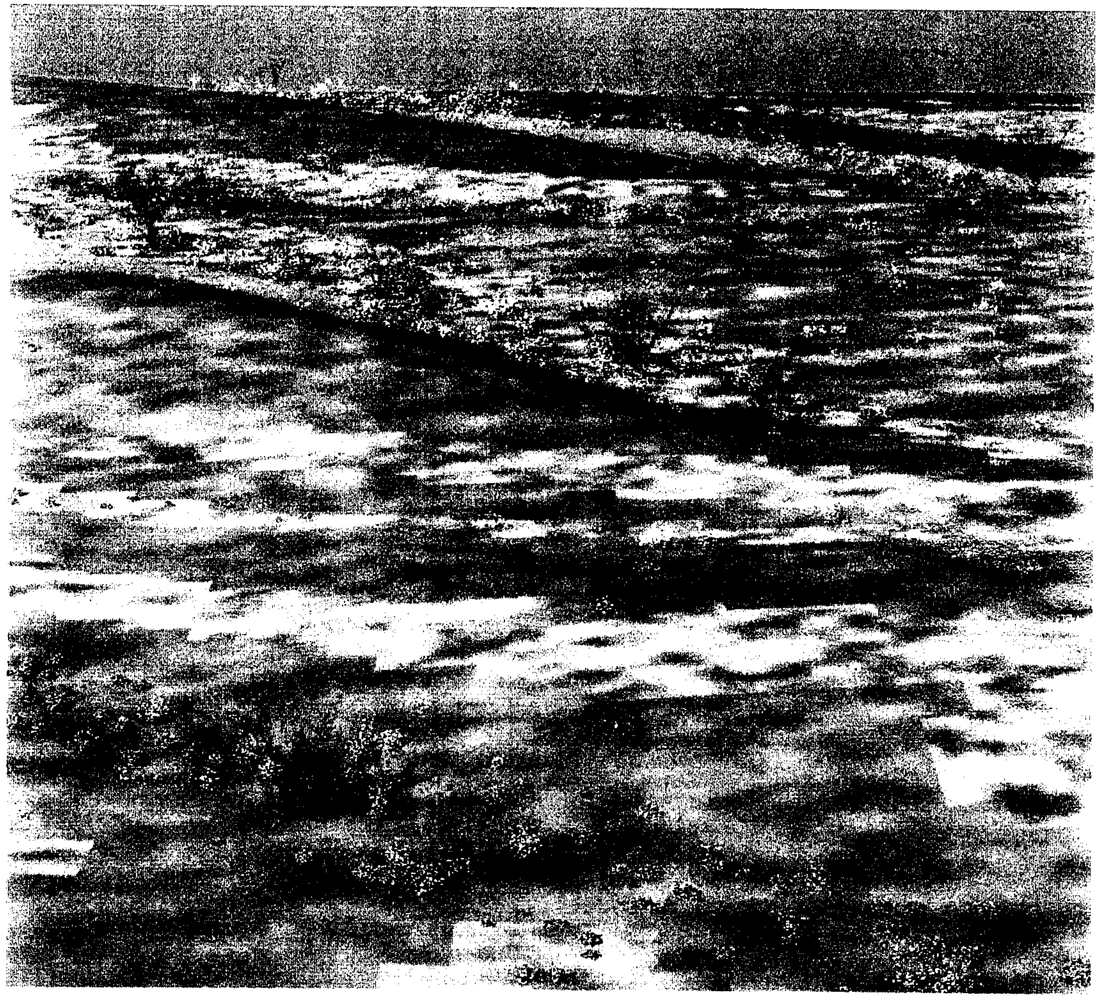

Figure 31. Three-dimensional graphical representation of information base facing toward western imaging area

Figure 32. Three-dimensional graphical representation of information base at 2 m from ground level facing a shallow wash

Figure 33. Three-dimensional graphical representation of information base facing the eastern imaging area. Both measured and interpreted vegetation basal locations are shown

Figure 34. Three-dimensional graphical representation of information base facing the eastern imaging area. Vegetation densities are shown varying with surface soil type

Appendix A
Information Base File Formats

These are the format specifications for the digital data used in the Smart Weapons Operability Enhancement (SWOE) scene generation procedure for the Yuma 1 Information Base.

File Name	Format	Description
elevation.asc	ASCII raster format	Floating point elevation data for models
elevation.[dgf,hgf]	CIG binary General Grid File (GGF) format	Floating point elevation data for SWOE scene generation
fid.asc	ASCII raster format	Polygon feature ID raster layer
fidsmc.col	CIG binary color format	Two layer feature ID and surface material code file used by SWOE scene generation
pfidp.inp	ASCII tabular format	Tabular index listing of polygon feature ID's and their associated surface material codes
usmc.inp	ASCII tabular format	Tabular index of surface material codes
<model_name>.wes	WES 3-D tree geometry ASCII format	An ASCII tabular listing of x,y,z, and diameters of the tree geometry
tree_loc.dat	ASCII tabular format	Geographic tree basal locations, tree models, and model scaling factor
*.met, *.sol	SWOE meteorological format	Yuma 1 Information Base meteorological data
daylist.dat	ASCII tabular format	Listing of all available days of meteorological data

Meteorological Data

The Yuma 1 Information Base contains two different files describing the meteorological conditions during the program: standard meteorological data

and solar flux data. A text description of the standard meteorological data (*.met files) is as follows:

line 1: General Information
line 2: Altitude of Station (meters above MSL), Latitude Longitude, Time Flag
line 3: Time Step, Number of Steps, Year, Season Flag, Dry Soils Flag
line 4,5: Day, Time, Pressure, Temperature, Relative Humidity, Wind Speed, Wind Direction, Visibility, Aerosol Flag, Precipitation Amount, Precipitation Type, Low Cloud Amount, Low Cloud Type, Medium Cloud Amount, Medium Cloud Type, High Cloud Amount, High Cloud Type, Global Solar, Direct Solar, Diffuse Solar, IR Downwelling, Solar Zenith, Solar Azimuth
lines 6-n: Data Values

The following FORTRAN format statement describes the data values format:

```
FORMAT (2I3,I2,F7.1,3F6.1,F7.1,F5.1,I4,F7.2,I3,1X,3[F4.1,I2],4[7.1],F6.1,
        F7.1)
```

A text description of the solar flux data (*.sol files) is as follows:

line 1-24: Julian Day, Hour, Minute, Low Cloud Amount, Weighted Total Solar, Weighted Direct Solar, Weighted Diffuse Solar, Clear Sky Total Solar, Clear Sky Direct Solar, Clear Sky Diffuse Solar, Overcast Total Solar, Overcast Direct Solar, Overcast Diffuse Solar

The following FORTRAN format statement describes the data values format:

```
FORMAT (I3,I2,I2,F3.1,9[F6.1])
```

These data values and procedures are described in detail in a report by Koenig entitled "Grayling 1 Data Review and Archive Databases."

Texture Data

Each texture image file contains 256 by 256 pixels of 8-bit binary gray level data with a 512-byte header. These conform to the Boeing Computer Image Generator (CIG) format specifications. Gray levels are normally distributed with a mean of 128 and a standard deviation of 32. Resolution cell size of the source imagery from which textures were generated is approximately 6.6 cm; therefore, each 256- by 256-pixel texture image corresponds to a square area approximately 17 m on a side.

Terrain Data ASCII Raster

The ASCII format for terrain data layers consists of two parts: (a) header section, and (b) data section. The header section is composed of free formatted 15 lines of ASCII text that describes the geographic region of the data layer. Below is an example:

```
YUMA PROVING GROUND AZ FOR SWOE/JT&E
NORTH-SOUTH RESOLUTION: 1.000000
EAST-WEST RESOLUTION: 1.000000
CENTER OF DATA (UTM): 756260.500000 E  3650826.000000 N
CENTER OF DATA (LAT-LON): 32.965734N 114.258266W
ZONE:  11
NORTH:  3651109.00
SOUTH:  3650543.00
EAST:  757152.00
WEST:  755369.00
NSRES:  1.00
EWRES:  1.00
ROWS:  566
COLS:  1783
```

The first line of the header section is text describing the title/region of the data layer. The second and third line indicate the resolution of the data in meters. Lines 4 and 5 provide the center of the data set in Latitude/Longitude and universal transverse Mercator (UTM) coordinates. Line 6 indicates the UTM zone of the data layer, and lines 7-12 describe the UTM boundaries and resolution of the data layer. Lines 13 and 14 specify the number of rows and number of columns in the data layer. Line 15 is left blank.

The data section is actual data values of the data layer; these data values can be either floating point values or integer. The data are in row-major order where data values run from west to east. The row data are arranged in order from north to south with each row ending in a carriage return (ASCII CR). Each data value within a row is separated by a blank space. Below is an example of a data section for two rows and four columns.

```
370.9 371.2 371.1 373.2
371.1 371.9 370.8 372.9
```

CIG Binary General Grid File (GGF)

The GGF format data are Latitude/Longitude floating point values with a 320-byte header section describing the location and size of the data file.

CIG Binary Color File

The CIG binary color format data are three-layer Latitude/Longitude integer values with a 512-byte header section describing the location and size of the data file. Typically, the first layer contains polygon feature IDs (FID) data; the second layer contains surface material code (SMC) data; and the third layer is left empty.

Appendix B
Physical Parameters

These are the suggested physical parameters for the thermal models used in the Smart Weapons Operability Enhancement (SWOE) scene simulation procedure for the Yuma 1 Information Base.

Physical Parameters for Yuma Terrain Types

	Terrain Types					
	Desert Pavement (sandy silty clay)		**Disturbed Desert Pavement and Secondary Washes (gravelly silty sand)**		**Washes (silty sand)**	
Parameters	**Layer 1**	**Layer 2**	**Layer 1**	**Layer 2**	**Layer 1**	**Layer 2**
Layer thickness, cm	3.0	30.0	3.0	30.0	3.0	30.0
Long-wave emissivity, percent	0.85	-	0.30	-	0.90	-
Shortwave absorptivity, percent	0.60	-	0.30	-	0.60	-
Thermal diffusivity, $cm^2\ min^{-1}$	0.45	0.50	0.50	0.50	0.35	0.50
Thermal conductivity, cal $min^{-1}\ cm^{-1}$ K-1	0.30	0.35	0.35	0.35	0.10	0.35

Note: See Table 5 in main text for descriptions.